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Volume 53, 1962

RESEARCH AND THE OYSTER INDUSTRY

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ABSTRACT

In an address to a joint meeting of oyster growers and biologists, it is pointed out that the oyster industry could be greatly benefited immediately if the knowledge already available were fully utilized. An "extension service" is proposed for the shellfish industry.

INTRODUCTION

One of the things I like about these Annual Meetings, which I have been attending regularly since I first came to Chesapeake Bay in 1951, is the close and friendly association it fosters between scientists and the industry. I think we have learned to know and respect each other over the years.

But I have suspected that we do not really understand each other very deeply and that we somehow are failing to help each other as much as we might do. After all, our shellfish biologists exist only to serve you, the shellfish industry. If the scientific information we produce is not fully utilized by industry, nor by State legislation and management agencies, then your investment in scientific research is not paying dividends.

I am going to talk about some of our failures—ours and yours as well. This may give you all some things to think about, and may start action that can lead the oyster industry out of its present slump. I am going to use the industry in Chesapeake Bay as an example, because this is the region I know best. But remember, any specific problems I mention are merely examples. I am not singling out particular people, organizations, or agencies for criticism.

OYSTER PROBLEMS

What are some of the principal problems of the Chesapeake oyster industry today? Uppermost in many minds, I am sure, is the so-called oyster blight, MSX. But this is by no means the only serious problem we face. Another problem, Dermocystidium, has killed large numbers of oysters in the past and will do so again. Oyster drills are a constant threat to planters in many areas, sea stars a recurring plague in others. The success of oyster setting varies widely from year to year, making the future uncertain. Oysters often do not grow well in places where setting is good. Grounds on which fattening is best are not necessarily good for setting or growth. These are some of the principal problems of biological origin.

But these are not all our troubles. Many physical factors threaten the success of your operations. Hurricanes and other severe storms may wipe out your crops by burying them in silt and mud. Unusually severe freshets, especially in summer, may kill without warning. Man-made troubles are even more disturbing, for they are becoming more frequent and troublesome as our cities and industries grow. Pollution from sewage can eliminate your harvest without killing a single oyster. Dredging, filling, bridge and tunnel building, and other engineering activities can do great damage. Industrial pollution can foul the waters so that only noxious pollution-loving forms can survive. Insecticides and radioactivity are relatively new sources of trouble, which cannot fail to increase as time goes on. Even such innocuous-appearing substances as the common household detergents now so widely used offer a yet unknown threat of injury to oysters and other estuarine animals.

WHAT HAS SCIENCE ACCOMPLISHED?

What have scientists done to help you with these problems? Much research effort has been devoted to MSX in the past two or three years. Yet we do not know the identity of the organism we call MSX, nor have we proven that it is the cause of death. We have learned a great deal about the geographic distribution, seasonal occurrence, and biological effects of Dermocystidium. Yet we have no direct method to control its lethal effects. We have developed several methods to control oyster drills. We believe that these methods are much more effective than the tedious and inefficient trapping method. Yet none of these methods is in general use in the oyster industry. We understand quite well the geographic and seasonal patterns of oyster setting. We have fairly extensive historical records of their annual variations. Yet we do not know how to control oyster setting in the natural environment. We know that oysters often set best in certain areas, grow best in other places, and fatten best elsewhere. Yet we do not understand the reasons for these differences and cannot control them. Someone has said, quite truthfully, that we probably know more about oysters than we do about any other marine animal. Have we made good use of this abundant biological knowledge? I do not think so.

Where do we stand with respect to the effects of physical forces, natural or man-made? We understand the biological effects of storms. Storms kill oysters not only by smothering them in mud or sand, but also produce side effects that kill by depleting the dissolved oxygen supply or by releasing toxic hydrogen sulphide. Yet we must stand helplessly by while these effects do their damage. We are equally powerless to influence the effects of freshets. We have achieved a considerable degree of control over the effects of domestic pollution, and a somewhat lesser, but still significant, control over industrial wastes. Yet pollution problems are with us continually, and they involve important issues that conflict often with fishery interests. Thus, we are achieving far less than we would desire in modifying the effects of pollution, and probably always will.

By proper planning and study we can mitigate the effects of engineering projects upon our oyster resources. Yet we cannot always anticipate these effects before the change is made. Problems related to proposed deepening of the James River channel, which passes through the heart of the Virginia seed oyster area, are a good example. Everything we know about the circulation of estuaries and the characteristics of oyster setting tells us that deepening the channel is apt to affect the seed-producing characteristics of the James River adversely. Yet, since we do not understand completely the characteristics of a good oyster setting area, and probably never will, we cannot be certain.

We are just beginning to develop scientific knowledge of the effects of radiation and of pesticides upon marine organisms. We have much to learn. We know that detergents have adverse effects upon organisms when present in sufficient quantity. We know that these substances may pass through sewage treatment plants almost unchanged. We know almost nothing of the effects of wastes of various kinds on maturation, spawning, setting, feeding, growth, mortality, and other characteristics of oysters. The complex and difficult problems presented by all these sources of pollution have led some people to suggest that the oyster culture of the future must be carried out entirely under artificial conditions, using the most modern scientific techniques. This certainly seems true in the immediate future for areas close to large human population concentrations. The Bureau has made considerable strides already in developing such techniques. We have plans for further development in the near future. But there are still large areas of virgin or near-virgin estuarine waters where scientific knowledge, if it is applied intelligently, can improve oyster quality and yield.

USING OUR SCIENTIFIC KNOWLEDGE

I have purposely painted a gloomy picture of the practical application of our scientific knowledge of oysters. I did this to develop the thought that our private viewpoints and public policies have been at fault. Let us look at our scientific knowledge from another point of view, from a direction that suggests how this knowledge can be put to practical use.

Previously I dealt with the principal biological problems of oyster growers from the standpoint of one who would attack them directly. This was consistent with the popular belief that we should solve them by frontal assault, as it were. It is obvious that our extensive scientific knowledge offers no immediate hope of direct control of epidemics of MSX or Dermocystidium. Industry has been slow to adopt or even test more effective methods of pest control. Biologists have a great deal of information on spawning, setting, growth, fattening and mortality, among other things, but they have not shown how these characteristics can be altered favorably by direct methods.

In other respects, however, there is a great fund of knowledge that shows how these problems can be attacked indirectly. The Virginia oyster, for example, is an estuarine animal. Under natural conditions it usually thrives best in waters of intermediate salinity. If it survives at all in saltier waters, it usually does so most successfully along the shoreline, where it is periodically exposed by the tides. What does this signify to the oyster planter? As far as Chesapeake Bay is concerned, it means that the upper limit of oyster distribution is determined by its ability to tolerate fresh water. Its seaward limit is set by the tolerance of its enemies and diseases to waters of reduced salinity. The oyster's principal advantage over these enemies and diseases is that it can survive and thrive in salinities that do not drop below five to seven parts per thousand for any considerable period, while its predators such as drills and starfish, and diseases like MSX and Dermocystidium, are not a serious problem in waters below 12 to 15 parts per thousand. Extensive areas in Chesapeake Bay lie within these limits of salinity (Fig. 1), and this zone includes most of the naturally producing oyster grounds. Some of this favorable water is unsatisfactory because the bottom is unsuitable, or for other reasons.

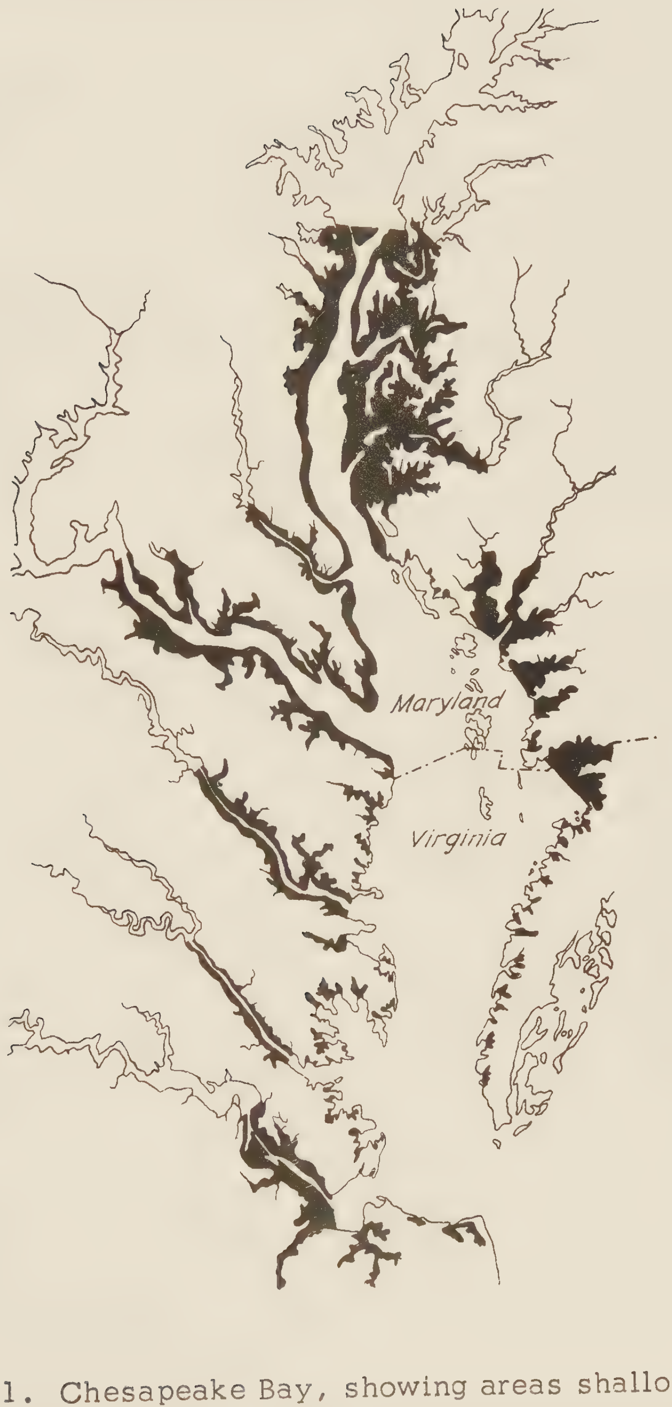

Fig. 1. Chesapeake Bay, showing areas shallower than 30 feet in the Bay and less than 20 feet in the estuaries, where salinities are favorable for oysters but unfavorable for their principal enemies and diseases. Where the bottom is suitable and other conditions are satisfactory, these are the areas most favorable for oyster planting.

But much of it could be utilized for oyster growing if local traditions and State laws permitted it. It is significant that in Virginia, for the most part, these favorable zones lie up the estuaries. The James River seed area and the public bars of the Rappahannock River are examples. In Maryland, on the contrary, a very extensive part of the Bay itself lies between these limits. This, then, suggests one way in which the problem of predators and disease can be solved directly. We could grow oysters in areas where these problems are absent. Is the industry taking full advantage of this knowledge? I do not think so.

Your immediate reaction may be—public opinion and policy are against this in many areas, and we are prevented by law from following your advice. My reply is: laws can be changed if public opinion favors change. How can we work with you to help you take advantage of accumulated scientific knowledge?

SEED OYSTERS

What is probably the greatest single seed oyster producing area in the world is concentrated in a short stretch of the James River. We do not know all the reasons for the great productivity of this area. We do know that it has continued to yield a bountiful harvest each year almost without fail, despite a heavy fishery. Nowhere else in the Bay is such a steady and heavy set of oyster spat obtained. Yet once set, these oysters grow quite slowly. The characteristics that favor spawning and setting obviously do not favor growth.

This very slowness of growth, however, favors this seed for planting in drill-infested waters in the lower part of Chesapeake Bay. Slow-growing oysters are thick-shelled oysters, and drills can penetrate thick shells only with difficulty. This is why an extensive oyster planting industry has managed to develop in the salty waters of the lower Bay, until the recent epidemic of MSX virtually wiped out this operation. If bottoms more favorable for planting, in terms of absence of drills and blight, had been open for leasing, these less favorable bottoms might never have had to be used.

The waste involved in the crude farming techniques employed in the Virginia parts of Chesapeake Bay is startling. I do not have accurate figures for the total numbers of oysters in a bushel of seed from the James River, for these oysters range in size from microscopic spat just recently set to oysters of market size. Because growth rates are slow in the seed area, many ages are represented in the seed harvest. The most abundant of all age groups, naturally, is the group that set during the year of harvesting. When harvesting begins in October, these newborn oysters, only about two months old, are very delicate. Probably none survives the multiple perils of damage during harvesting, desiccation on board the tonger's boat and the buy-boat before replanting, and smothering by mud and silt or predation by drills and other enemies shortly before replanting. This means that at least half of the seed harvested in the James River is wasted.

There are several ways in which much of this waste could be avoided. It might be practical to delay the seed harvest until spring, when these newly born young will have increased to a size more able to withstand transplantation. Survival could be increased substantially if bottoms could be leased in waters of lower salinity. Seed would be used more efficiently if economical methods could be developed to plant cultch in seed areas and transplant the spat each year. Have we done everything possible to solve these problems? I do not think so.

Even the traditional methods of harvesting and marketing oysters work against the best interests of the oyster grower. The old myth of the "R" months has had much to do with this, I suspect. Oystering traditionally begins in fall, shortly after the end of the spawning season. At this time the meats are perhaps at their poorest, thin and watery with poor reserves of glycogen, the animal starch that gives plump oysters their sweet and delicate flavor. Moreover, summer is the greatest period of stress for the oyster in other ways. All biological activity is at its peak. Many oyster pests and diseases are in their most active period. In the saltier waters of the lower Chesapeake, where most planting acreage is located, biologists know that summer mortalities of 25 to 50% are not uncommon. This means that, in many years, from one-fourth to one-half the oysters alive on these grounds at the end of June will be dead by October. Moreover, the growth rate of adult oysters slows down in summer. There is very little gain in size to balance these substantial losses by death.

If you were to harvest your crop in late spring, about four or five months earlier than usual, you would gain in at least three ways. Your oysters would not be appreciably smaller. You would harvest perhaps one and one-third to twice as many bushels. Each bushel would yield perhaps twice as many pints of meats. These meats would be of prime quality, at their fattest and tastiest. It would not be unusual to produce twice to four times the usual yield of shucked meats by adopting this simple change in harvesting practice. I can hear some of you saying the price would be lower, because demand is poor at that season. This is primarily a matter of tradition, I think.

People's habits can be changed, or methods can be developed to preserve these prime meats, for sale when market conditions are at a maximum. Have you done everything possible to take advantage of this knowledge? I do not think so.

HAS PUBLIC MANAGEMENT SUCCEEDED?

In most oyster producing states the naturally producing grounds have been set aside as public grounds, either to produce seed for planting on barren leased ground, or for harvesting market-size oysters directly. Many states spend considerable sums to protect and rehabilitate these grounds. I think we would all agree that these efforts have not been entirely successful. Combined oyster production of Maryland and Virginia has declined from 22 million bushels in 1890 to less than 6 million in 1961. When oystering began, the entire crop was harvested from public grounds. Now about three-quarters of Virginia's production comes from formerly barren grounds leased to private planters. Many formerly productive public bars in Virginia now are barren. These could be returned to production under private mangement, but state laws and local traditions are opposed to leasing of public grounds, even if they produce no oysters.

The decline of the Potomac River oyster industry has been well documented. Toward the end of the nineteenth century the total area of productive natural oyster ground in this river reached the impressive figure of 42 square miles. Today the productive area is only a quarter this size, and yields per acre almost certainly are lower. The newly created Potomac River Fisheries Commission has the opportunity to create oystering history by taking bold steps to reverse this trend.

THE FUTURE

These matters are far more complicated than I have indicated here. To introduce all the complications in a short talk would hide the point I am trying to make. To stimulate thought and discussion, I am going to make a positive statement that none of you may accept. It is simply this: I believe that if the favorable characteristics of Chesapeake Bay and its estuaries for oyster culture had been used to their maximum, the oyster industry would not be suffering the difficulties it suffers today. Please give this matter some serious thought. The knowledge necessary to establish a rational system of scientific management has been available for many, many years. Tradition and prejudice have prevented maximum use of scientific and practical knowledge.

We could, even today if we were free to do so, revolutionize the oyster industry. Almost any good oysterman could write out a plan. The basic knowledge could be drawn on charts, showing the areas in which oysters can thrive but where their principal enemies and diseases cannot. Other charts might show setting areas, growing areas, and fattening areas. Our knowledge is not perfect by any means; but if all available information were brought together, its extent might surprise us all. Armed with such a compendium of knowledge, an atlas of oystering conditions if you will, we then could draw up a master plan for utilizing these areas to their maximum. We could even make rough estimates of the increases in yield and quality that might ensue, and take a stab at making cost estimates. With such a plan, we could attack the difficult problem of securing general support from all segments of the industry, then from state legislatures. We might be surprised to find that changes are not so difficult to make as we have suspected.

AN ATLAS OF OYSTER GROUNDS

The blackened areas on Fig. 1 are those areas of suitable depth with salinities favorable to oysters but unfavorable for their major enemies and diseases. Most of these areas are not available to private planters. It is obvious that most planting grounds now under lease are outside this optimal area. Oystering has been sufficiently profitable, and planters have been fortunate enough to escape serious natural disasters, so that it has been possible to continue planting these marginal grounds. But the recent onslaught of MSX has demonstrated the danger of such practices. This is the time to put our knowledge to work. The atlas will be a most useful document. It will bring together the knowledge of scientists, and the accumulated experience of oystermen. No one with an open mind can deny the conclusions that it is certain to bring.

This atlas of oystering conditions will not resemble the crude chart represented by Fig. 1. It will be based on a much larger scale, which will permit detailed identification of bottom types and all the other pieces of information we will need to know. It will be developed in consultation with all the people who have pertinent knowledge. It will not be assembled overnight, for it will require much painstaking research and discussion. But it may well become the most important document that your industry could possibly have.

As scientific knowledge grows, these favorable areas can be extended. Presently proposed methods of oyster drill control, when they are proven, will allow a considerable extension. The time may come when control of oyster blights may be possible, either by direct methods, or by breeding resistant strains. Whatever the future may bring, the atlas will provide a useful base.

The atlas might be useful in dealing with man-made problems also. It might, for example, show areas where industrial and domestic expansion could take place without serious damage to the oyster industry. It might show where dredging, filling, and other engineering developments should and should not be undertaken. It might well lead to a concept of zoning our estuarine waters for maximum development of all such uses, with minimum damage to fishery resources.

A SHELLFISH EXTENSION SERVICE

For some time we in the Bureau have been considering the advisability of organizing an extension service for the shellfish industry. We believe that we have failed in our responsibility to communicate our scientific knowledge to you. Only by providing a group of knowledgeable people, who can work with you and help you to develop the information you need, can we make progress. This group would assist in testing the effects of changes in oystering methods and make sure that these trials were properly designed and adequately tested. Their first job would be to bring together the information and develop the plans I have outlined. Their continuing responsibility would be to improve the basic knowledge on which the plan was based. Then they would feed this knowledge back into their planning, to the benefit of industry. We hope to put such an extension service into operation soon. As we develop our plans, we would like to have the help of industry, state scientists and state administrators. As a team, I believe we can accomplish miracles. Shall we begin?

Redd Superimposition and Egg Capacity of Pink Salmon Spawning Beds[1]

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ABSTRACT

A study of egg recruitment to pink salmon spawning beds in two southeastern Alaska streams (Indian Creek and Harris River) has shown that egg loss during spawning increases as the density of female spawners increases. Mortality was caused for the most part by superimposition of redds.

A mathematical model of spawning success is derived. The model assumes that the curve describing the recruitment of eggs to a spawning bed is asymptotic and that pink salmon females spawning within any defined spawning ground select the sites of their redds at random. The model is used to estimate the asymptotic limit of the egg recruitment curve for a Harris River spawning bed. Levels of mortality associated with various densities of spawning female pink salmon are predicted for Harris River from the model.

INTRODUCTION

THERE IS EVIDENCE that the capacity of a spawning bed to produce fry is impaired by excessive numbers of adults spawning. Ricker (1954, 1958), Neave (1958), and Wickett (1958, 1962) reported that the average yield of fry approached an upper limit as the density of spawners approached an "optimum level". Ricker concluded that maximum fry yield would most likely be realized by allowing spawners to attain a density intermediate between low and high (curve A, Fig. 1). A mathematical model describing an asymptotic relation (curve B, Fig. 1) between egg deposition and recruitment of juvenile fishes has been developed by Beverton and Holt (1957).

Important objectives of research on pink salmon (*Oncorhynchus gorbuscha*) are to understand factors that place an upper limit on the potential of spawning beds to produce fry and to determine the optimum density of adults that should be allowed to spawn. This paper considers one problem pertaining to these questions—mortality from redd superimposition during spawning.

Redd superimposition becomes an important mortality factor for Pacific salmons at high spawning densities (Gilbert and Rich, 1937; Smirnov, 1947; Morgan and Henry, 1959). In one instance, mortality of pink salmon eggs was estimated to be near 90% at high spawning densities (Semko, 1954). The question of competition for spawning space between pink and sockeye (*O. nerka*) salmon in the Karluk River system, Alaska, was considered by Rounsefell (1958), who concluded that large escapements of pink salmon caused a significant reduction in the reproductive potential of sockeye salmon because of crowding on the spawning beds.

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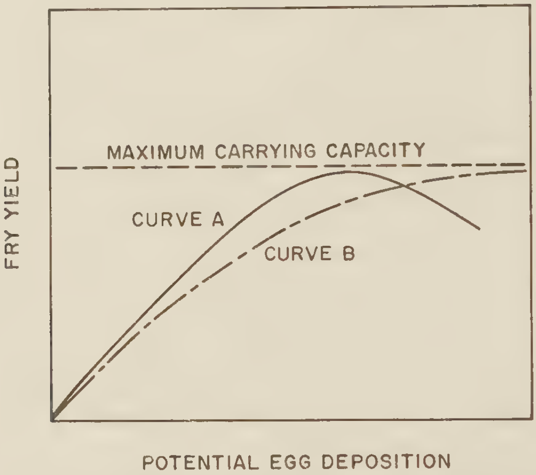

FIG. 1. Postulated relation between potential egg deposition and fry yield of pink salmon. See text for discussion of curves.

The number of fry produced from a spawning bed cannot exceed the number of eggs present at the end of spawning; hence, redd superimposition might place an ultimate upper limit on the potential of spawning beds to produce fry. It is postulated that egg displacement from the spawning bed increases as the density of spawning females increases, ultimately reaching a point where females displace from the spawning bed a number of eggs equal to the number they deposit. In this paper, evidence showing a direct relation between egg loss and density of females spawning is presented; and a mathematical model of spawning success is developed. The model is used to estimate the egg capacity of a pink salmon spawning bed in a southeastern Alaska stream and to predict mortality from redd superimposition.

FIELD STUDY METHODS

The success of pink salmon spawning was evaluated in two southeastern Alaska streams—Harris River and Indian Creek—which are located on Prince of Wales Island about 40 miles west of Ketchikan. Observations were made on intertidal spawning beds utilized almost exclusively by pink salmon. The Harris River study area encompassed 6093 m^2 and the Indian Creek study area 3905 m^2.

A measure of spawning success was obtained from observed differences between two population estimates (1) the number of pink salmon females estimated to spawn in a study area, and (2) the equivalent number of females required to deposit the number of eggs estimated to be present in the study area after spawning. Methods used to obtain these estimates will be described.

ESTIMATING NUMBER OF FEMALES SPAWNING

The number of pink salmon females spawning in each study area was estimated by counting daily those that were digging and protecting redds and by determining from tagging studies the average length of time a female remained on the spawning ground. The method is illustrated with pink salmon spawning in Harris River in 1960.

The number of pink salmon females counted daily in the Harris River study area is shown by an eye-fitted curve in Fig. 2. The area under the curve represents 31,700 female days. To obtain an estimate of the average duration a pink salmon female occupied the spawning ground, 38 tagged pink salmon females were observed daily. This gave an average of 9.8 days. One day was added to the total because it was assumed that the average female was present one-half day before the time of the first observation and one-half day after the time of the last. The number of females spawning in the Harris River study area was estimated to be

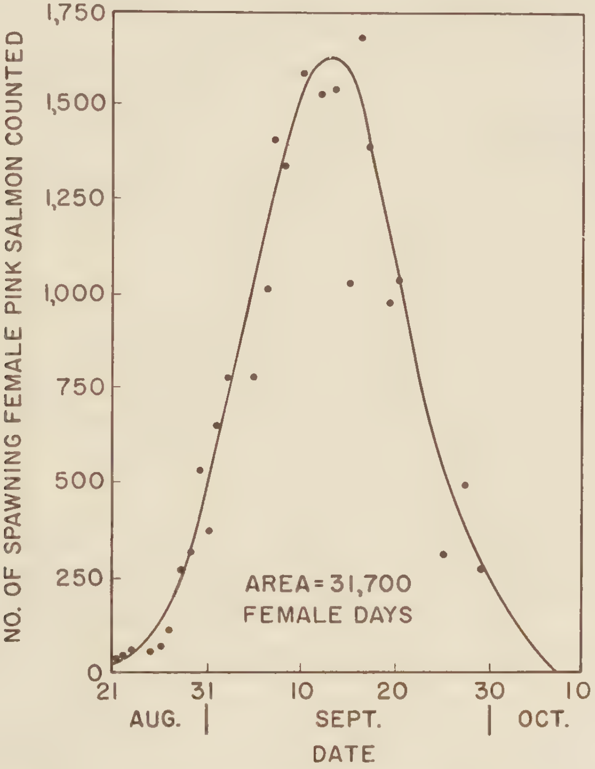

FIG. 2. Daily counts of female pink salmon spawning in the Harris River study area in 1960.

$$\frac{31{,}700 \text{ female days}}{10.8 \text{ days}} = 2930 \text{ females.}$$

Similar estimates were made for other brood years in Harris River and for Indian Creek. The method and its assumptions are described in more detail by McNeil (1962).

Estimating Equivalent Number of Females Spawning Safely

The abundance of eggs in each study area was estimated by sampling with a hydraulic sampler after spawning (McNeil, 1962). An equivalent number of females spawning safely (i.e. without having their eggs subsequently dislodged) was calculated by dividing the estimated number of eggs in a study area by the assumed average fecundity of pink salmon[2].

Differences between the estimated number of females spawning and the equivalent number spawning safely were thought to be a measure of voided eggs lost during spawning, because very few eggs were found in body cavities of the spent females examined. At low spawning density, there was good agreement between the expected and observed density of eggs in spawning beds; and with the possible exception of 1961, losses at higher spawning densities were attributed mostly to redd superimposition. Flooding occurred before postspawning sampling in 1961 and may have accounted for much of an observed high egg loss.

SPAWNING SUCCESS

A major purpose of this study was to develop analytical methods for predicting egg capacity of spawning beds from estimates of spawning success. The methods described are based on two assumptions: (1) spawning success is limited primarily by redd superimposition, and (2) egg capacity approaches an asymptotic limit with increasing density of spawners. Results of field studies in Indian Creek and Harris River support these assumptions.

Field Observation of Spawning Success

Pink salmon usually spawn in Indian Creek and Harris River during September, and sampling to estimate egg abundance was done between late September and early November after the end of spawning. Density of female pink

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[2] Average fecundity was assumed to be 1700 eggs per female (see Rounsefell, 1957).

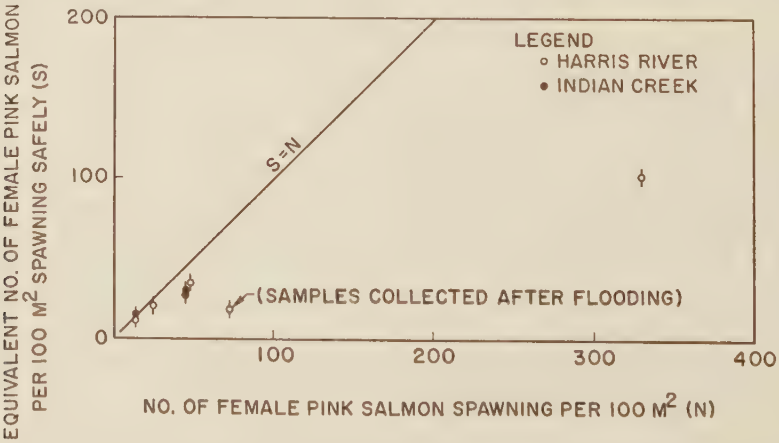

FIG. 3. Observed relation between number of female pink salmon spawning and equivalent number spawning safely. Lengths of vertical bars correspond to 90% confidence interval estimates of population mean.

salmon spawning in the Indian Creek and Harris River study areas and the equivalent number of females estimated to have spawned safely are given in Table I. It is noteworthy that the estimated equivalent number of females spawning safely (S) was consistently less than the estimated total number of females spawning (N), where $N > 24$ females per 100 m². Values of S are plotted against their corresponding values of N in Fig. 3 to illustrate the observed relation between these parameters.

TABLE I. Estimated number of female pink salmon spawning and equivalent number required to spawn safely to deposit the number of eggs estimated to be present in the study areas after spawning, Harris River and Indian Creek.

Study area and year	Estimated number of females spawning per 100 m² (N)	Estimated equivalent number spawning safely per 100 m² (S)	
		Mean	90% confidence limits of mean
Indian Creek			
1958	12.9	15.5	±6.7
1959	46.3	26.9[a]	±7.6
1960	46.3	28.6	±8.6
Harris River			
1958	12.9	12.4	±6.0
1959	24.8	19.6[a]	±4.6
1960	48.4	35.1	±7.8
1961	73.0	18.2[a b]	±6.5
1962	330.0	101.7	±15.9

[a] Samples collected on two dates and having mean values not differing significantly were pooled to obtain a single estimate.

[b] Samples were collected after flooding.

MODEL OF SPAWNING SUCCESS

The model assumes that the equivalent number of females spawning safely approaches an asymptote as the density of spawners increases. Figure 4 illustrates the hypothetical relation between total spawners (N) and the equivalent number laying their eggs safely (S). The asymptotic limit of the equivalent number of spawners that can deposit their eggs safely is designated as "L".

To assist in understanding the model and its assumptions, we will first consider a spawning bed to be represented by a "checkerboard" pattern. Each square of the checkerboard will be equivalent to the average area excavated by a female. The number of squares will equal the number of such sites available for spawning (L), and each female is assumed to select a square at random, i.e. independent of whether or not spawning had previously occurred at the site. Squares receiving more than one female will retain, on the average, a number of eggs equivalent to that deposited by one female.

In a natural spawning bed redds lack the symmetry described by the checkerboard model, and also, redds would in most instances be partially rather than totally superimposed. We will assume that the frequency of occurrence of partially superimposed redds is proportional to the degree of superimposition. Thus the number of eggs lost from superimposition would be equivalent to that of the checkerboard model, and the simplifying assumption that spawning sites are arranged in checkerboard pattern would not affect the model.

The most questionable assumption is that of random distribution of females. Because female pink salmon establish and defend territories during spawning, the assumption that occupation of positions by earlier spawners does not influence the choice of spawning sites by later spawners might not be strictly correct. Questions requiring further investigation include: (1) How long does a female effectively defend her territory? (2) How specific is the location of her territory in relation to the points at which she deposited her eggs? (3) What influence does increasing spawning density have on territorial behaviour?

The equation used to describe spawning success is:

$$S = L(1-e^{-N/L}) \qquad \ldots (1)$$

Equation 1 can be derived by two methods—from a differential equation and from the Poisson distribution.

Derivation from a differential equation. With each small increment in N (ΔN) there will occur a small increment in S (ΔS) (see Fig. 4). The increments ΔS will decrease in size as N increases and ΔN is held constant. The size of an increment ΔS will be proportional to the probability that a female entering a spawning ground will select a site which had not already been utilized by another female for spawning. Thus, the increment in S is the increment in N

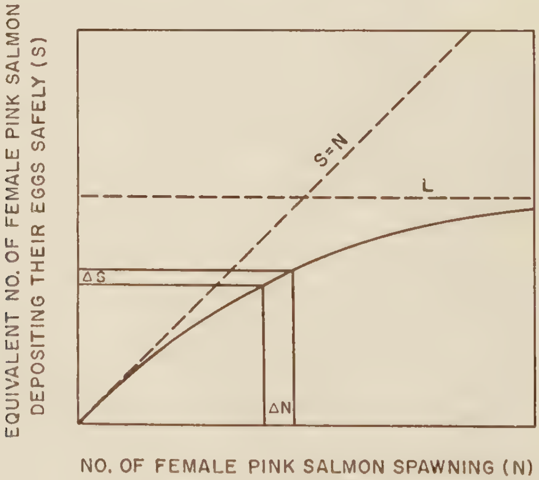

Fig. 4. Relation between number of females spawning in a given area and the equivalent number depositing their eggs safely. ΔS is an increment in S associated with an increment in N(ΔN).

multiplied by the proportion of the area not previously utilized for spawning at the time ΔN occurs, i.e.

$$\Delta S = \frac{(L-S)}{L} \Delta N \qquad \ldots (2)$$

Equation 2 is assumed to be independent of time; hence, spawning behaviour is assumed to be constant throughout the spawning period. Dividing by ΔN and taking the limit as $\Delta N \to 0$ gives:

$$\lim_{\Delta N \to 0} \frac{\Delta S}{\Delta N} = \frac{dS}{dN} = \frac{(L-S)}{L} \qquad \ldots (3)$$

where the function is continuous, positive, and single valued between $S = 0$ and $S = L$.

Integrating Equation 3 gives:

$$-ln(L-S) = \frac{N}{L} + C \qquad \ldots (4)$$

or:

$$L-S = C' (e^{-N/L}) \qquad \ldots (5)$$

The value:

$$C' = L \qquad \ldots (6)$$

is obtained by letting $N = 0$.

Substitution of Equation 6 in Equation 5 leads directly to Equation 1:

$$S = L(1-e^{-N/L}).$$

Derivation from the Poisson distribution. Let r be the number of females spawning per available site and let λ be the expected mean frequency of females spawning per available site. In this instance, r is assumed to follow the Poisson distribution where the probability of success can be considered to be a continuous, non-negative function of the number of independent trials (Koopman, 1950; Dixon and Massey, 1957). We thus obtain:

$$\text{Prob}(r) = \frac{(\lambda^r)\ (e^{-\lambda})}{r!} \qquad \ldots (7)$$

$$\text{Prob}(r=0) = e^{-\lambda} \qquad \ldots (8)$$

$$\text{Prob}(r \neq 0) = (1-e^{-\lambda}) \qquad \ldots (9)$$

The proportion of sites utilized by at least one female is $(1-e^{-\lambda})$; hence,

$$\frac{S}{L} = (1-e^{-\lambda}) \qquad \ldots (10)$$

The expected mean frequency of females spawning per available site is:

$$\lambda = \frac{N}{L} \qquad \ldots (11)$$

It follows from Equations 10 and 11 that the number of females depositing their eggs safely (S) is Equation 1:

$$S = L(1-e^{-N/L}).$$

EGG CAPACITY OF SPAWNING BEDS

Equation 1 can be expressed in linear form, viz.:

$$ln(L-S) = -\frac{1}{L}(N) + lnL \qquad \ldots (12)$$

where $-\frac{1}{L}$ is the slope and lnL is the point of intercept on the ordinate. By obtaining estimates of N and S, a graphical technique can be used to estimate L. The method will be illustrated with data from Harris River (Table I). The 1961 estimates are not included because flooding occurred before S was estimated and may have caused the removal of significant numbers of eggs from the spawning bed.

After a trial value of L ($L \geq$ the largest estimated value of S), Equation 12 is drawn with slope $= -\frac{1}{\hat{L}}$ and y intercept $= ln\hat{L}$. Values of $ln(\hat{L}-S)$ are calculated for each observed S and are plotted against the corresponding values of N. Different values of $\hat{L}$ are tried until the plotted points exhibit the least deviation from the theoretical line (Equation 12). This is the value accepted as the best estimate of L.

For Harris River, the following numbers of females spawning per 100 m² (N) and the numbers spawning safely per 100 m² (S) were used to estimate L:

	N	*S*
1958	12.9	12.4
1959	24.8	19.6
1960	48.4	35.1
1962	330.0	101.7

Figure 5 shows the line obtained from Equation 12 where L = 106.4 females per 100 m². Larger and smaller trial values of L exhibited greater departure from their theoretical lines, so a value L = 106.4 females per 100 m² of spawning ground was accepted for intertidal Harris River.

Provided each female deposits 1700 eggs, the egg capacity of a spawning bed where L = 106.4 females per 100 m² is

$$\frac{(106.4)\ (1700)}{100} = 1809 \text{ eggs m}^2.$$

This is approximately equivalent to the potential deposition of one female pink salmon per square meter.

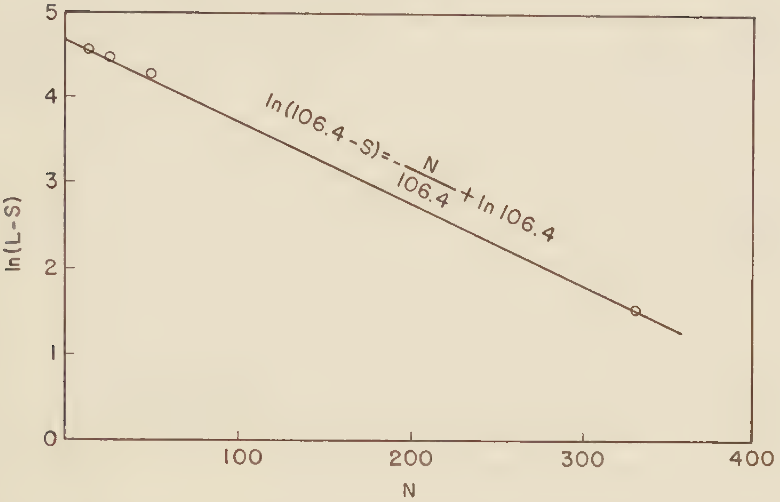

FIG. 5. Line of equation (12) drawn with slope $\left(-\frac{1}{L}\right)$ equal to $-\frac{1}{106.4}$. The plotted points are for Harris River and show the degree of correspondence between the theoretical line and the field observational data.

PREDICTED MORTALITY DURING SPAWNING

If the model adequately describes the dynamics of egg recruitment to the spawning bed and a value of L has been determined with a degree of accuracy commensurate with sampling variations, an estimate of the total mortality percentage (M_t) can be calculated. The number of females required to give any selected number spawning safely can be obtained by solving Equation 12 for N, i.e.

$$N = L(ln L) - L[ln(L - S)] \qquad \text{. . . (13)}$$

For example, the number of females required to spawn per 100 m² for an equivalent number of 50 to spawn safely (i.e. S = 50), where L = 106.4 is:

$$N = 106.4(ln\ 106.4) - 106.4[ln(106.4 - 50)] = \frac{68.1 \text{ females}}{100 \text{ m}^2}.$$

The mortality percentage can be calculated from:

$$M_t = \frac{(N - S)}{N}(100) \qquad \text{. . . (14)}$$

and in this instance is found to be 27%. Figure 6 shows how the predicted mortality changes with increasing density of females spawning where L = 106.4 females per 100 m².

CONCLUSIONS

The development of a successful management program for pink salmon will depend in part on the ability of management biologists to assess fry production potential of spawning beds and optimum escapement of adults to spawning streams. It will be necessary to determine eventually these attributes for each important spawning area and spawning stock.

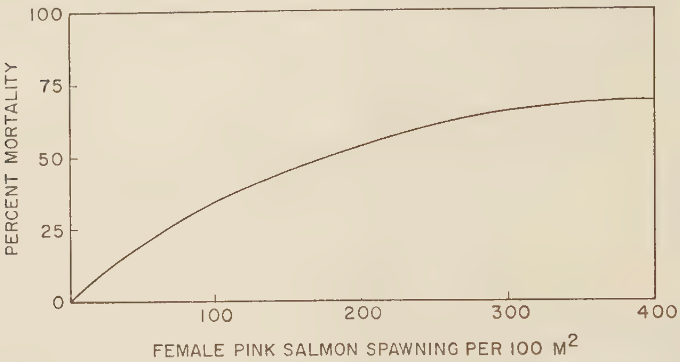

FIG. 6. Predicted relation between density of female pink salmon spawning and egg mortality during spawning where L = 106.4 females per 100 m^2.

Fry production potential of a spawning bed might ultimately be limited by mortality factors directly related to density of spawning adults. A mathematical model describing the dynamics of mortality from redd superimposition has been advanced in this paper. The model was used to estimate egg capacity of a spawning bed and to predict mortality during spawning. A basic assumption of the model is that females distribute themselves at random over a spawning bed. Further research is required to test the validity of this assumption.

Although redd superimposition is thought to become an important mortality cause at high spawning densities, the potential of a spawning bed to produce fry is possibly limited by additional factors. The oxygen delivery rate, for example, may exert a pronounced influence on carrying capacity. It has been observed, on the other hand, that females remove much extraneous organic matter from spawning beds while excavating redds (Semko, 1954; McNeil and Ahnell, 1964). The removal of eggs through redd superimposition and the cleansing of spawning beds of organic detritus may help the young salmon avoid stresses associated with oxygen privation and help protect them from epidemic outbreaks of pathogenic agents. Redd superimposition may thus be an essential mechanism inhibiting catastrophic mortality due to overcrowding.

In stream areas where spawning occurs over an extended period, mortality from redd superimposition would have its greatest impact on the progeny of early-spawning fish; and in years of large escapement, it is conceivable that late-spawning fish could nearly destroy the progeny of early-spawning fish. The relations between time of spawning and survival potential of young pink salmon are poorly understood. A working hypothesis might be that eggs from a single spawning stock deposited during the middle portion of the run possess a higher survival potential than eggs deposited very early or very late. It is assumed that hereditary differences associated with time of spawning do not exist within the stock. If competition for space on spawning beds becomes critical, as it might in years of great abundance, then the population of embryos surviving at the conclusion of spawning will have originated for the most part from the adults spawning late in the season. The population might arrive, therefore, at a state where its survival potential is greatly impaired because of the lateness of egg deposition.

ACKNOWLEDGMENTS

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Tuna Behaviour Research Programme at Honolulu

Abstract

The behaviour research programme of the Biological Laboratory of the U.S. Bureau of Commercial Fisheries at Honolulu is conducting studies of the sensory abilities and the behaviour of tuna. The methodologies of the comparative psychologist and ethologist are being utilised to gain a basic understanding of the ways in which a tuna responds to its environment. At present, detection of underwater sound, feeding behaviour, social behaviour, vision, and the changes in behaviour throughout the day are being investigated. These studies are conducted at sea using underwater viewing ports in the research vessel *Charles H. Gilbert* and in a floating raft, *Nenue I*, and in eight shoreside tanks at Kewalo Basin, Honolulu.

Le programme de recherche, à Honolulu, sur le comportement du thon.

Résumé

Dans le cadre du programme de recherche sur le comportement du poisson, le Laboratoire biologique de l'U.S. Bureau of Commercial Fisheries à Honolulu, conduit actuellement des études sur les facultés sensorielles et le comportement des thons. Les méthodologies de psychologie et d'éthologie comparatives ont été utilisées pour arriver à une base de compréhension de la façon dont réagit le thon à son environnement. Jusqu'à ce jour, la vision, la détection des sons sous-marins, l'habitude alimentaire, le comportement social et les changements de comportement durant la journée ont été observés. Ces études ont été conduites en mer, à travers des hublots sous-marins montés dans la coque du bateau de recherche *Charles H. Gilbert*, sur un radeau flottant, le *Nenue I*, et dans hit bassins à Kewalo Basin, Honolulu.

Programa de investigaciones del comportamiento del atún en Honolulu

Extracto

Como parte del programa de investigaciones del comportamiento del atún, el Laboratorio de Biología de la Oficina de Pesca Industrial de los E.U.A. en Honolulu, estudia la capacidad sensorial con relación al comportamiento. Se emplea la metodología de la sicología y etiología comparativas para tener un conocimiento básico de la manera en que el atún reacciona ante su ambiente. Actualmente se investigan la vista, la determinación de los sonidos subacuáticos, el comportamiento durante la alimentación y en sus relaciones con otros miembros del cardumen y los cambios del comportamiento durante el día. Estos estudios se realizan en la mar empleando los portillos submarinos del buque investigador *Charles H. Gilbert*, en una balsa flotante *Nenue I* y en ocho estanques en la costa en Kewalo Basin, Honolulú.

by
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Bureau of Commercial Fisheries, Hawaii

TUNA behaviour studies are one of eight major research endeavours of the Biological Laboratory of the U.S. Bureau of Commercial Fisheries at Honolulu. The objective of the behaviour research is to gain a basic understanding of the behaviour and the sensory abilities of tuna. An understanding of tuna behaviour is expected to be useful in the future design of fishing gear and fishing methods and in locating tuna.

The research programme was originally conceived in 1957 as a study of stimuli which attracted or repelled tuna to or from pole-and-line tuna fishing boats. Between 1958 and the present the orientation of the research has slowly changed toward a more general query with the potential of more generalised application.

Both a sea phase and a shore phase were begun in 1958. The first problem of each was to develop methods of studying the fast swimming pelagic tunas. Progress in these efforts was reported for the sea phase by Strasburg and Yuen (1960)[4] and for the shore phase by Nakamura (1962)[3]. By 1960 the oceanographic research vessel *Charles H. Gilbert* had been equipped with stern and bow underwater viewing ports, and feeding behaviour of tuna had been observed and photographed at sea. By 1961 the skipjack, *Euthynnus pelamis*, had successfully been kept and studied in shoreside tanks at Kewalo Basin, Honolulu, for almost six months. In 1962 a 12 ft by 12 ft raft with a viewing chamber beneath it was

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While a large body of information has been accumulated there are still many unknowns concerning the detailed behaviour responses of fish, both to natural environmental, and to artificial influences. This is largely due to the difficulties of observing fish in the sea directly. The recent development of high resolution echo sounders and techniques of underwater observation, and the growth of experimental aquarium work have, however, provided basic information. Work involving personal observation of fish in the sea, under varying environmental conditions and throughout the diurnal light cycle, is needed in order to confirm the pointers obtained from aquarium studies and by applying less direct methods. The need for appropriate underwater vehicles or chambers, for conveying observers to depths up to 80-100 fathoms. cannot be too strongly stressed. The use in the U.S.S.R. of a submarine with observation windows for this purpose is especially interesting.[7]

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designed and built by R. Gooding and was successfully used as a passive observation platform to observe and photograph dolphin fish, *Coryphaena hippurus*, and other large predators at sea. By the end of 1962, a total of eight tanks had been designed and erected for specific investigations at Kewalo Basin. In 1963 these facilities are being used by six biologists and aides engaged in analysing the enigmas of tuna's behaviour.

Two types of study are being conducted, those of sensory ability and those of behaviour. The methodologies of the comparative psychologist and the ethologist are being applied to species whose ways have long been observed by fishermen. Application of these methods is increasing the rate at which understanding of tuna behaviour increases.

Both visual and hearing abilities are being quantified with captive tuna at Kewalo Basin. The tuna are taught to associate an underwater sound or image with food or, in some cases, an electric shock. After training is completed, the tuna reacts to the visual or sound stimulus in the absence of the food or electric shock. The conditioned response indicates that the sound or image was perceived by the tuna's sensory system. A careful choice of stimuli make it possible to describe the ability of the sensory system to perceive the environment in standardised and generalised terms.

More specifically, the visual acuity of little tuna, *Euthynnus yaito*, and skipjack is presently being measured. Such data provide information on the ability of these tuna to see an object of a certain size at various light intensities and distances underwater. In the sound studies the range of frequencies tuna can perceive and the minimum intensity that can be perceived at each frequency are being described.

Behaviour research both at sea and in shoreside tanks is concentrated upon feeding behaviour, social behaviour, and changes in behaviour throughout the day and night. Most sea work is directed at skipjack and, yellowfin, *Thunnus albacares*, whereas most shore work is on skipjack, little tuna and bonito, *Sarda chiliensis*. The work on bonito is in co-operation with J. Prescott at Marineland of the Pacific in California.

At sea the stern underwater ports on the *Charles H. Gilbert* have provided an opportunity to observe feeding behaviour of tuna. Experiments were conducted in the waters of Hawaii and the Line Islands to determine the influence of different species of bait and artificial feeding stimuli on the feeding behaviour of skipjack (Yuen 1962)[7]. The fishing techniques of the Hawaiian sampan fleet were used: skipjack found by looking for bird flocks, were attracted to the vessel by chumming live bait into the sea, and were then caught on pole-and-line. Measurements were made of changes in catch rate and in the feeding rate (number of feeding attacks per fish per minute), which resulted from changing from live to dead bait, from one species of bait to another, or from turning off and on a water spray over the surface of the water. Catch rate increased when water sprays were turned on and decreased when they were turned off, when any one of six different species of chum was used. Both catch rate and feeding rate increased when living bait was chummed and decreased when dead bait was chummed. Catch rate is higher with the live bait, because movement is one of the stimuli inducing feeding behaviour of skipjack, and because dead bait tends to drift away behind the vessel and take the skipjack away with it. Experiments using different species of bait are still in progress.

While being fished by the pole-and-line techniques, surface schools of skipjack characteristically dive or sound, returning to the surface seconds or as long as 28 min later (Strasburg 1961)[5]. Zero to eight dives were observed per school in Hawaiian waters and the frequency of diving was found to be associated with the occurrence of a lizard-fish, *Synodus variegatus*, and a squirrelfish, *Holocentrus lacteoguttatus*, in the stomach contents of the skipjack. It was hypothesised that these two species were more attractive than the live bait used by the fishermen and that the skipjack dived in pursuit of them.

Tuna schools are usually composed of fish of the same species and approximate size. Occasionally, pole-and-line or purse seine tuna boats catch both skipjack and yellowfin in a single fishing operation. Observations from the stern chamber of the *Charles H. Gilbert* have made it possible to study the structure of the school or schools from which such mixed catches are made (Yuen in 1963)[8]. When underwater movie sequences of such schools were analysed, it was obvious that each species tended to school with its own kind even though fish of the other species were near. A higher frequency of groups of a single species was observed than would have been expected if the fish schooled indiscriminately with the other species.

The floating observation raft is being used to discover the ecological significance of floating logs or flotsam to pelagic fishes. The reason that large numbers of dolphin fish and occasionally yellowfin and skipjack are found in the immediate vicinity of floating objects has been a debated question among fishermen for years. This study should provide some insight into the problem.

The three underwater viewing ports in the bow of the *Charles H. Gilbert* have been used to observe tuna, porpoise, flying fishes, and large plankton organisms. Most small fish dart rapidly away from the moving ship, but tuna and porpoise swim within view of the bow windows for prolonged periods of time. The bow viewing ports made it possible to observe in detail the behaviour of porpoise when riding the bow wave (Yuen 1961).

Very loose schools of skipjack have been observed in the central Pacific, with 7 to 18 yards between fish. These schools, 3 to 6 ft beneath the surface, were only one fish deep. During periods of observation when small numbers of natural prey were sighted by the skipjack, a vertical barred colour pattern appeared on the skipjack, and two or three of the fish nearest the prey organisms converged on them and fed. We have not yet succeeded in observing tuna in a feeding frenzy on natural prey concentrations, although we have attempted to do so by

heading the ship through areas marked by the surface splashes of feeding fish. Although the tuna were sighted by the underwater observer, they dived immediately and were not visible for prolonged periods.

Observations from the bow chamber on large plankton organisms in daylight and, by their luminescence, at night were interesting but difficult to record in numerical terms. It is hoped that the bow chamber can be used to estimate the abundance of surface fishes, but perhaps its greatest value will continue to be as a tool for making observations on marine mammals and fishes as the ship is actually moving with and within surface schools.

Direct observations at sea can be made on tuna that are either attracted near the observer by food stimuli, floating objects, or some other attractant, or that can be successfully followed at distances within 100 ft. This limits the spectrum of behaviour which can be observed at sea to feeding and schooling. In the shoreside tanks other aspects of behaviour can be examined, and feeding and schooling behaviour can be given closer scrutiny.

On shore the detailed patterns of tuna behaviour are first described. Whenever possible the function of the behaviour is determined. If the function is not obvious, experiments are devised to define the utility of the behaviour to the tuna. The functions of most of the observed patterns of behaviour have not yet been recognised. At present certain mouth movements, believed to be important in olfaction and food searching behaviour, are being investigated. The possibility of an olfactory function to the tuna's mouth movements was suggested by an anatomical study of the olfactory capsule of skipjack by Gooding (in 1963)[1]. An accessory sac of the olfactory capsule is compressed when the mouth is closing and inflated while the mouth is opening. This pumping seems to suck water into the naris and over the olfactory sense organ with each opening of the mouth.

Another interesting behaviour of tuna is the change from the typical striped coloration to a vertically barred coloration in skipjack (Nakamura 1962)[3]. This change results when a food stimulus is presented to a skipjack that has not eaten recently. A skipjack that has just eaten its fill does not take on the vertical pattern. The significance of this colour change is not yet known.

In addition to describing behaviour patterns and attempting to determine their function, the changes in behaviour, especially feeding motivation, occurring throughout the day are also being studied. The time of day when a tuna contacts prey and the amount of prey contacted can be expected to greatly influence the response of tuna to food stimuli during successive hours. For example, if skipjack are fed to excess all day long, they eat over half the food they will take during the day in the first three hours of daylight (Nakamura 1962)[3]. Presently, the variations in response to food are being associated with the previous prey-contact history of a tuna.

The present state of knowledge on tuna behaviour was recently summarised by Magnuson (in 1963)[2]. The inability to observe tuna behaviour directly at sea prior to 1958 greatly restricted the accumulation of knowledge. Now the tuna, still evasive and difficult to work with, is subject to the close scrutiny of the ethologist and comparative psychologist both in the field and in the laboratory. The understanding that these studies are providing should give man an additional advantage over the tuna in future exploitation.

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24. ACTIVITY PATTERNS OF SCOMBRIDS

Scombrid fishes are characterized by continuous swimming. This is associated in various degrees with search for food, gill ventilation, and maintenance of hydrostatic equilibrium. These three functional aspects of swimming are being investigated by studies of the activity patterns of scombrids in shoreside tanks (24 feet in diameter, and 3 feet deep) at Kewalo Basin.

Quantitative data on activity, measured as swimming speed, are obtained from an observation window in a tower overlooking the tanks. A Plexiglass board, parallel to the tank's surface, is inserted into the frame of the observation window. Sheets of clear plastic acetate paper are laid over the board and the path of the fish swimming in the tank is traced by an observer onto the acetate sheet with a wax pencil. While tracing, the observer views the tank from a fixed position through the acetate paper and Plexiglass. The length of the path, traced over a known time interval, is measured from the paper with a map measurer and converted to distance traveled by the fish and swimming speed. The distances between the window, the tank, and the observer's eye determine the conversion factor. In the present situation, 1 cm. on the acetate paper equals 24 cm. in the tank.

Wavyback skipjack, *Euthynnus yaito* Kishinouye, which have been in the tank for a month or so, swim at the same slow speed (about 0.9 m/sec for a 0.4 m. fork-length fish) throughout the day and night in the absence of food stimuli. If deprived of food for several days, speed decreases to about 0.6 m/sec, only to increase again following a meal. The average density of five intact *E. yaito* was 1.074 gm/cc, their food 1.071 gm/cc, and their sea water environment 1.024 gm/cc. Based on these density measurements, a 1 kg. *E. yaito* would weigh about 50 gm. in sea water and would tend to sink. Following a meal of 100 gm., its weight in water would increase by about 5 gm., because the food was also more dense than sea water. Since these fish swam faster when their stomachs were full and since they received lift while swimming from the planing action of their pectoral fins, it appears that the increase in speed following a meal results in part from the increase in weight.

Another adaptation to maintain hydrostatic equilibrium is the swim bladder. This organ is absent in *E. yaito* and in many other scombrids. All scombrids without swim bladders are relatively small species, less than 30 kg. in maximum recorded weight, whereas at least eight of those species with swim bladders attain sizes in excess of 30 kg.; some grow over 100 kg. A 100 kg. tuna without a swim bladder would weigh about 5,000 gm. in water if it had the same density as *E. yaito*. It can be speculated that the planing action of pectoral fins can be sufficient for the amount of lift required by smaller species, but that additional adaptations such as swim bladders are necessary for species with greater mass and heavier weights in water.

Analyses such as those presented in this abstract are being conducted on the activity patterns of scombrids to determine the effects of the functional components of locomotion on their behavior.

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U. S. Bureau of Commercial Fisheries

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Role of zooplankton in the freshwater strontium cycle and influence of dissolved salts[1]

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With 6 figures and 2 tables in the text and on 2 folders

Introduction

In aquatic organisms, the concentrations of radioisotopes are often reported, not in absolute terms, but relative to the concentration of the same radioisotopes dissolved in the water. The concentration factor for strontium is given by the ratio, $Sr^{90}_{(org)} : Sr^{90}_{(env)}$, where $Sr^{90}_{(org)}$ represents the absolute concentration (microcuries per gram live weight) in the organism and $Sr^{90}_{(env)}$ represents its absolute concentration in the water (dissolved).

Prediction of Sr^{90} uptake by marine organisms will be relatively simple compared with the same task with freshwater forms because of the relatively uniform chemical composition of sea-water and the fact that many freshwater species inhabit waters ranging widely in calcium content. Because of the chemical similarity of calcium and strontium, the $C.F._{(Sr)}$ for a freshwater organism is not likely to be a constant. In biogeochemical investigations of strontium, it is customary to deal with neither absolute concentrations, nor concentration factors, but rather with Sr/Ca ratios (Odum 1957).

In assessing the potential hazard of Sr^{90}, or in predicting its biological fate (equilibrium concentration factors) in terrestrial food chains, extensive use has been made of the relationship: $(Sr^{90}/Ca)_{acceptor} = OR(Sr^{90}/Ca)_{precursor}$, where OR stands for observed ratio, which is essentially equivalent to "discrimination factor". In order that this relationship be used with validity in predicting Sr^{90} uptake, the OR must be a constant or a known function of time and environment. Also, the calcium and strontium must be thoroughly mixed and combined with similar anions in the precursor (Kornberg 1959).

The purpose of the present paper is to suggest the importance of certain plankton Crustacea in the freshwater strontium cycle and to test the applicability of the OR equation for predicting Sr^{90} uptake by an aquatic organism.

Methods

In one experiment, the amount of Sr^{85} uptake in 20 isolated adult *Daphnia magna* was determined at frequent intervals over a period of more than eight days, spanning three complete molt-cycles. The individual animals were radioassayed in a well-type scintillation counter. They were generally not removed from their Sr^{85} labeled medium for more than 1—10 minutes at a time. A few individuals were transferred to unlabeled media at different points on the Sr^{85} uptake curve of the third molt-cycle in order to determine the rate of loss of strontium.

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[1] Contribution No. 8, Great Lakes Research Division, Institute of Science and Technology, The University of Michigan.

In another experiment, the relative importance of food versus water (direct uptake) as sources of strontium in *Daphnia* was determined by comparing the amount of Sr^{85} taken up when both food and water were uniformly labeled with uptake when labeled water alone was available.

The relative importance of metabolic uptake versus adsorption (non-metabolic uptake) was determined by an experiment in which the amounts of Sr^{85} taken up by newly-secreted exoskeletons alone (recently molted *Daphnia* from which most of the trunk had been removed) and *Daphnia* whose metabolic rate had been retarded by dilute KCN, were compared with the amount taken up by normal, actively metabolizing controls.

Finally, two experiments were performed using a wide variety of waters from natural sources which were doubly labeled with the radioactive tracers Ca^{45} and Sr^{85} in order to test the potential applicability of the OR equation to prediction of Sr^{90} uptake by an aquatic animal. *Daphnia magna* was chosen as a convenient test-organism for both experiments.

In these experiments, portions of each kind of water received identical inoculations with both Ca^{45} and Sr^{85} and several adolescent instars of *Daphnia* which had been cultured since birth in the same type of water except for the absence of tracers and the presence of *Chlamydomonas reinhardi* as food. This transfer was made just before the molt preceding the first adult instar. When, from prior experiments, it was known that Sr^{85} uptake had reached equilibrium, the *Daphnia* were removed, rinsed, and further prepared for radioassay. The Ca^{45} (beta) activity was determined by use of GM counter, and the Sr^{85} (gamma) activity was determined by use of a well-type scintillation counter.

The water samples used in these experiments were collected from a spring, four small lakes, three rivers, and three of the Great Lakes (Table 1). The water from Lake Erie was a composite sample from Sandusky Bay and the open lake. The composite sample of Lake Superior water came from three sampling points among the Apostle Islands of western Lake Superior. The research vessels, Musky II, Cisco, and Siscowet, of the United States Bureau of Commercial Fisheries collected the samples in Lakes Erie, Michigan, and Superior. Water from the various sources was stored in polyethylene bottles prior to the start of the experiments and chemical analysis.

The chemical analyses were made in the Ann Arbor Biological Laboratory of the Bureau of Commercial Fisheries on water that had been aerated for 12 hours in preparation for the experiments. The analytical methods employed are based on those in *Standard Methods* (American Public Health Association, 1955) with some minor modifications in procedure. Determinations for hydrogen ion concentration

Table 1. Source of Waters.

Water	County	Township	Range
Ann Arbor Spring	Washtenaw	2 S	6 E
Bishop Lake	Livingston	1 N	5 E
Burt Lake	Cheboygan	35, 36 N	3 W
Chocolay River	Marquette	47 N	24 W
Douglas Lake	Cheboygan	37 N	3 W
Lancaster Lake	Cheboygan	37 N	3 W
Silver River	Baraga	51 N	32 W
Trout River	Presque Isle	35 N	5 E
Great Lakes			

Erie, Sandusky Bay and 5 miles NE of the Bay Michigan, 3 miles W of Saugatuck, Michigan Superior, Apostle Islands area.

(p^H) were made with a Beckman Model G p^H meter. Total alkalinity was determined by the methyl-orange indicator method. A Beckman DU spectrophotometer with a flame attachment using an oxyacetylene flame was employed for calcium (wave length 554 mu), potassium (wave length 768 mu), and sodium (wave length 589 mu). Concentrations of magnesium were estimated from data for calcium and total alkalinity. The resulting approximations for the waters from Lakes Michigan and Superior agree to within 1 —2 ppm with our previous analyses for magnesium in samples from these lakes. Chloride was determined by the mercuric nitrate titration using diphenylcarbazone-bromphenol blue as an indicator. A Fischer AC electrophotometer was used for the turbidimetric sulfate determination. The colorimetric heteropoly blue method was used for determination of silica concentrations. The Beckman DU spectrophotometer was employed to measure the color development. Resistance measurements were made with an Industrial Instruments Type RC-16B-1 conductivity bridge and a pipette cell. Resistance was converted to specific conductance in mhos/cm $\times 10^6$ at 18° C (K_{18}) by the following formula:

$$K_{18} = \frac{10^6}{R_t\ (1 + C \triangle t)}$$

where R_t is the measured resistance, C is the temperature coefficient of conductance at t, and $\triangle$ t the difference in temperature between 18° C and temperature of test measurement.

Results and Discussion

A typical result from our first experiment (Fig. 1), in which the Sr^{85} content of individual *Daphnia magna* adults was determined at frequent intervals for a period of more than eight days, shows that over 95% of an animal's strontium content at equilibrium is in the exoskeleton, with which it is eliminated upon molting. This was verified by radioassay of the shed exoskeletons. Other experiments showed that a first instar adult contains, at equilibrium, an average of 6.7 micrograms of calcium, which is equivalent to approximately 0.81% of their total live weight. Our limited observations with *Daphnia pulex* and *Ceriodaphnia*

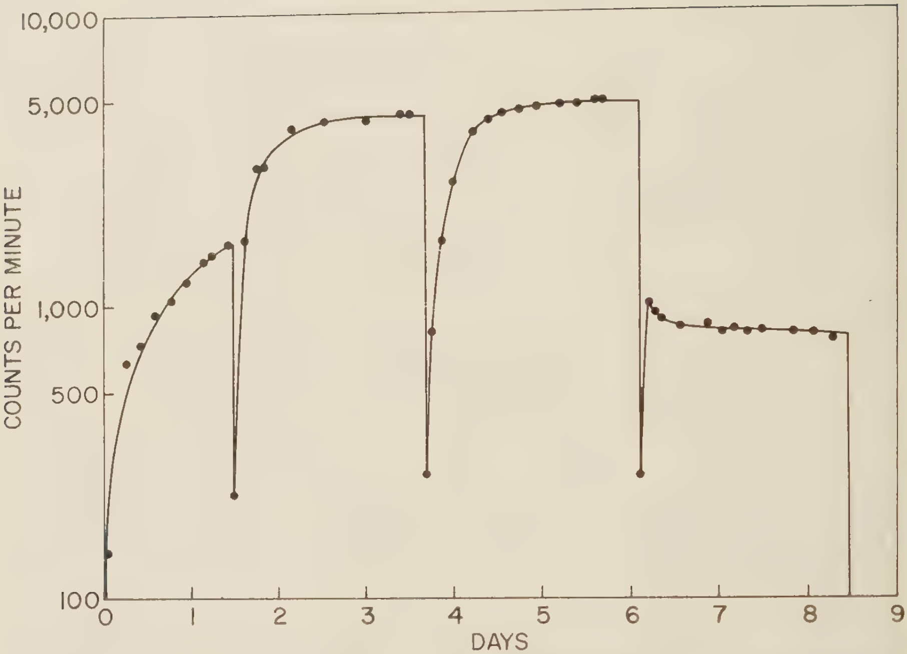

Fig. 1. Semi-log plot of Sr^{85} uptake in an adult *Daphnia magna* over a period spanning three complete molt cycles. Last cycle shows loss of Sr^{85} after being transferred to unlabeled medium shortly following third molt. Curves fitted by eye.

reticulata, as well as some older Ca determinations by others for *Daphnia pulex* and *Leptodora* sp. (VINOGRADOV 1953) indicate that other Cladocera contain less calcium than *Daphnia magna.* Nevertheless, it now seems quite probable that plankton Crustacea play an important role in the freshwater strontium cycle. Dense populations of limnetic species might account for a significant proportion of the total calcium and strontium (including Sr^{90}) removed from the epilimnion of a stratified lake — not so much through the settling of dead plankton as through the continual shedding of exoskeletons by the living.

Shortly after its third molt (Fig. 1), this animal was transferred to unlabeled medium. The slight negative slope established there indicates that the rate of loss is negligible compared with the rate of uptake. Other animals, which were transferred to unlabeled media after they had almost reached equilibrium, showed that the loss rate is equally slow at that time.

The kinetics of strontium uptake appear to be first order (Fig. 2). If $Sr_{(t)}$ represents the strontium content at a given time since molting (t), $Sr_{(eq)}$ the strontium content at equilibrium, and k the specific rate constant, the uptake curve can be described by the equation: $Sr_{(t)}/Sr_{(eq)} = 1 - e^{-kt}$. This model has also been shown to describe strontium uptake by recently molted crayfish (SCHURR and STAMPER 1962). From the time for half-equilibrium, $T_{1/2}$, the specific rate constant for individuals 4.0 mm in length, at 25° C, was estimated to equal $0.12\,hr^{-1}$ (Fig. 2).

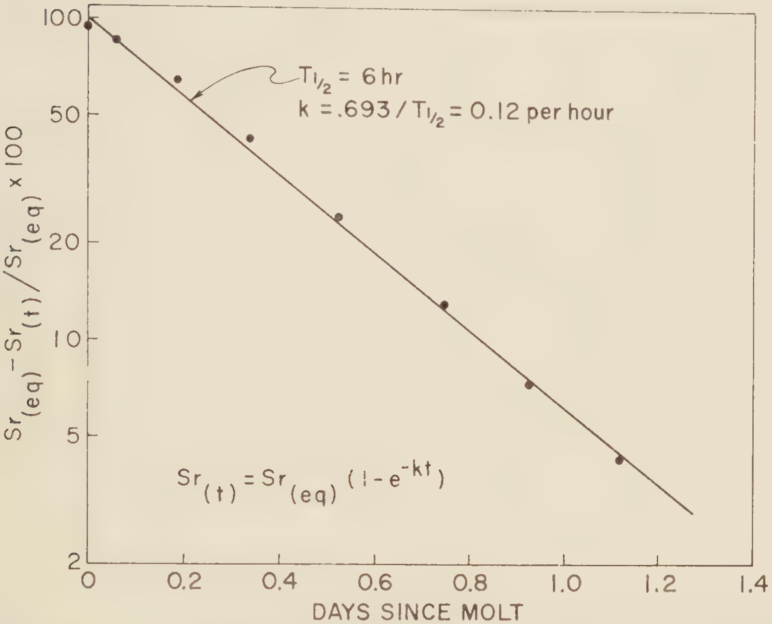

Fig. 2. Semi-log plot of Sr^{85} remaining to be taken up by adult *Daphnia magna* in order to reach equilibrium (expressed as a percent of the equilibrium value) against time since preceding molt. Line fitted by eye.

Fig. 3 shows the results of an experiment designed to determine whether the mechanism of uptake involved metabolic, active transport or simply external, surface adsorption. A preceding experiment had already shown that less than 5% of an animal's strontium content at equilibrium was accounted for by food in the digestive tract and that feeding was not necessary for one normal uptake cycle. The uppermost curve, labeled "controls", shows the normal uptake pattern (Fig. 3). The bottom curve, "trunk removed", shows the uptake by newly secreted exoskeletons alone and indicates that adsorption probably accounts for less than 5% of the normal equilibrium uptake. This leaves us with metabolic uptake (absorption), which seems to be confirmed by the pronounced depression of uptake (shown in the middle curve) produced by the metabolic poison, KCN (Fig. 3). These animals also showed a reduced heart rate and swimming activity. They finally died after about ten hours, and the negative slopes of this and the bottom curve indicate the rate of loss of strontium from decomposing exoskeletons.

The concentration of Sr^{90} dissolved in aquatic environments, $Sr^{90}_{(env)}$, is probably independent of their concentration of dissolved calcium, $Ca_{(env)}$. If so, the expected equilibrium concentrations of Sr^{90} in a given species, as well as the equilibrium concentration factors for strontium, $C.F._{(Sr)}$, will be proportional to the reciprocal of the environmental calcium concentration, $Ca_{(env)}$ (assuming the OR is a constant, independent of time and the chemical composition of the environment).

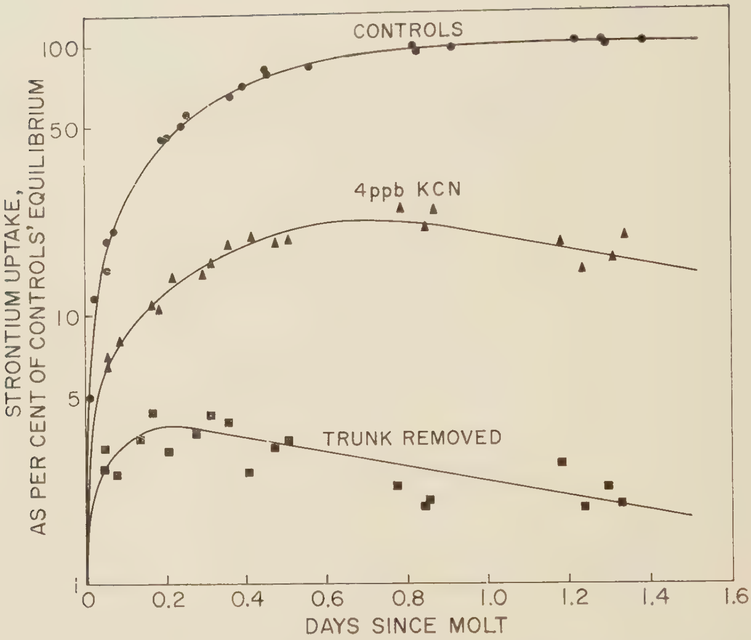

Fig. 3. Semi-log plot of Sr^{85} uptake by adult *Daphnia magna* (as percent of controls' equilibrium) against time since preceding molt using: a) four adults from which most of the trunk had been removed, b) four which were metabolically retarded by presence of dilute KCN, and c) four normal controls. Curves fitted by eye.

In aerated spring waters which had been prepared from a single source by various dilutions with distilled water, the observed values of $C.F._{(Sr)}$ for *Daphnia magna* do, indeed, seem to be adequately predicted by the OR relationship, as indicated by the fairly good fit made by the expected, reciprocal curve (Fig. 4). The hyperbolic relationship predicted by the OR equation suggests that the potential Sr^{90} hazard rises precipitously as one considers the more oligotrophic lakes. Also, since metabolic energy is required to regulate $Ca_{(org)}$, the vertical asymptote of the upper curve (Fig. 4) might indicate that $Ca_{(env)}$ becomes a limiting factor for *Daphnia magna* around 5 –6 ppm. Since all of the major ions were in constant relative proportions in this experiment, this was not a particularly critical test of the predictive value of the OR equation. We therefore decided to test it using a wide variety of natural waters.

The results of chemical analyses on the waters collected for this test (including the undiluted spring water used in the preceding experiment) are shown in table 2. The various major ions in this series of waters are present not only in different concentrations but also in quite diverse relative proportions. Since Mg is in the same chemical group as Ca and Sr, it might be expected to influence the cycling of Sr just as Ca does. Notice, therefore, that Mg is poorly correlated with Ca in this series of waters. Total alkalinity is also poorly correlated with Ca.

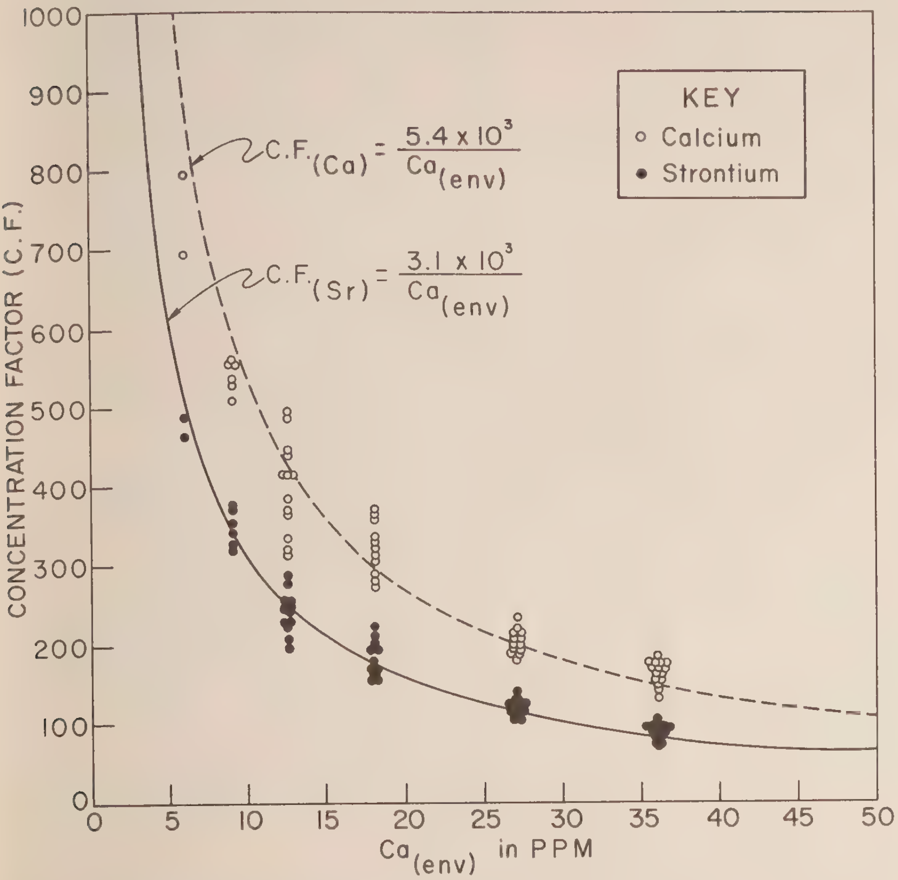

Fig. 4. Arithmetic plot of equilibrium concentration factors for strontium and calcium in 66 adult *Daphnia magna* against environmental calcium concentration, using spring water diluted with different proportions of distilled water. Equations for both curves are indicated.

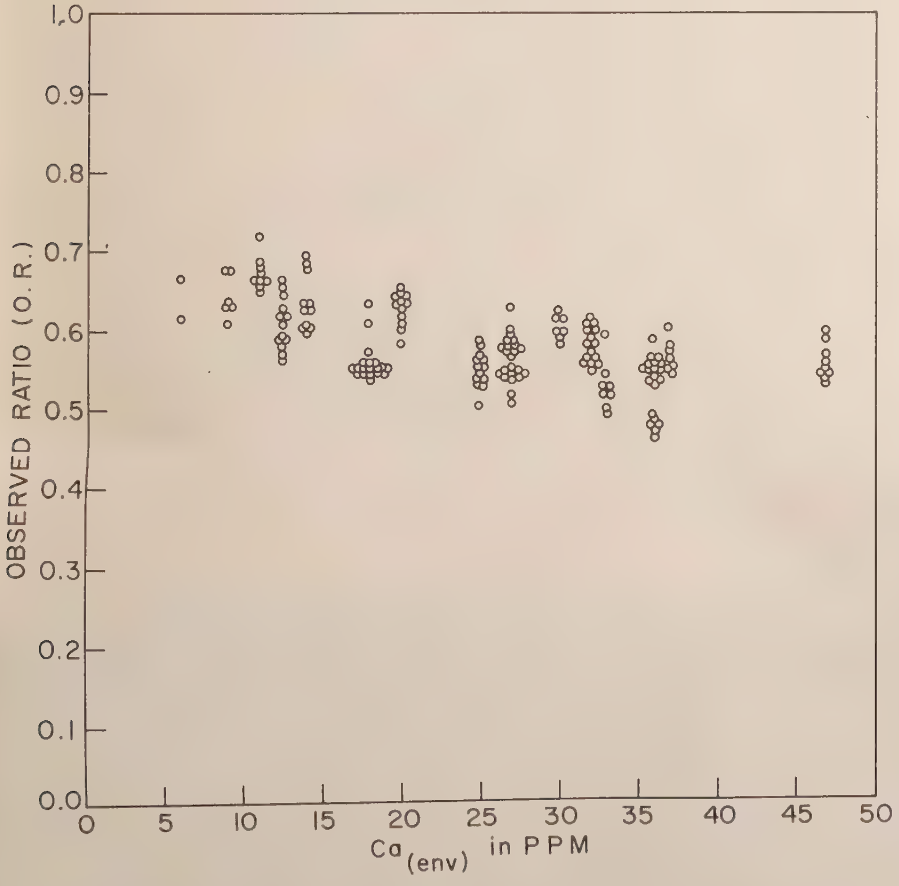

Fig. 6. Arithmetic plot of observed ratio, $(Sr/Ca)_{org} : (Sr/Ca)_{env}$, for 171 adult *Daphnia magna* against environmental calcium concentration, using natural waters from eleven different sources.

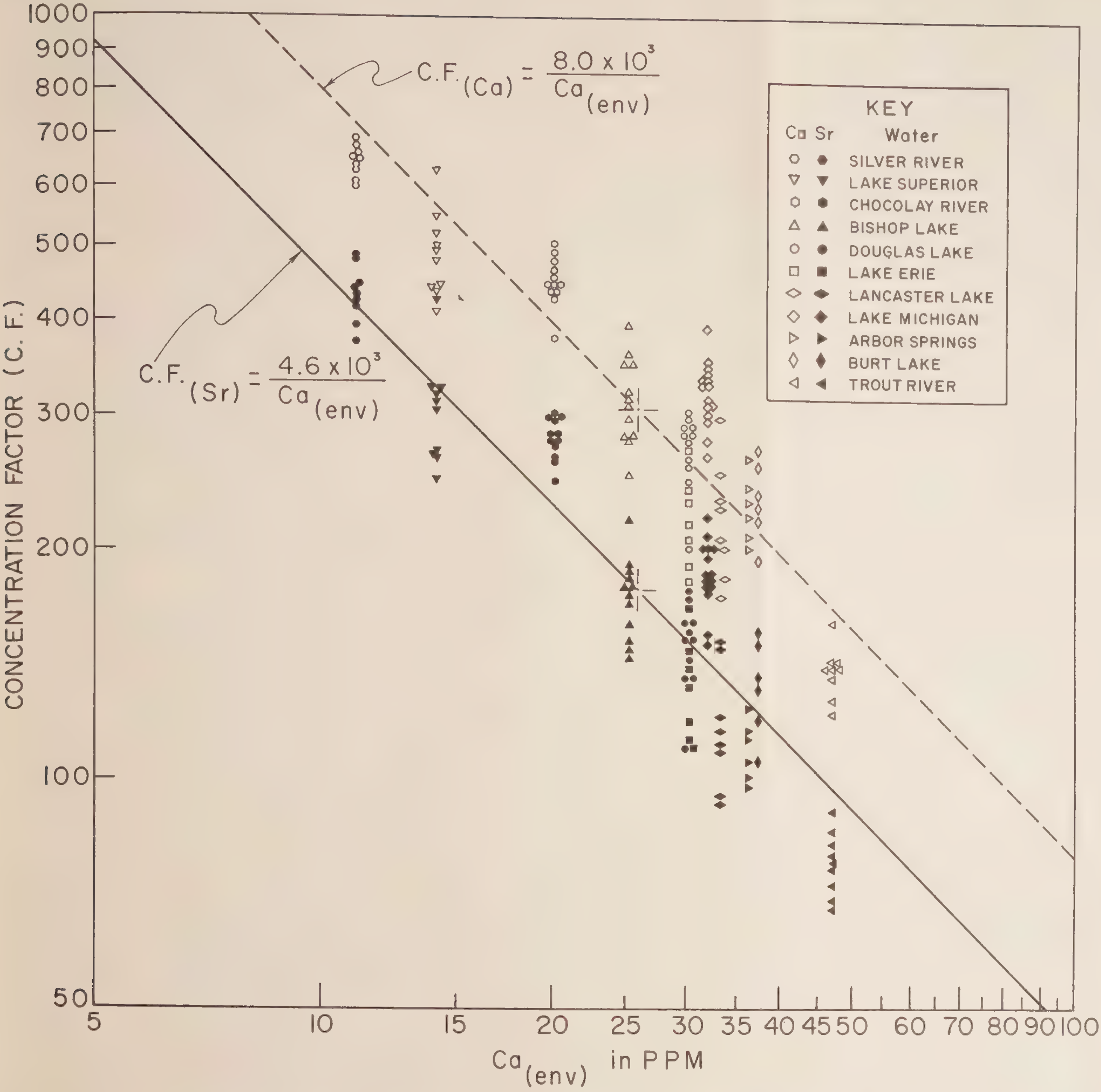

Fig. 5. Double-log plot of equilibrium concentration factors for strontium and calcium in 105 adult *Daphnia magna* against environmental calcium concentration, using natural waters from sources indicated in key. Equations for both curves are shown. Each proportionality constant is product of numbers corresponding to mean logarithms of coordinates for all points. Coordinates of points corresponding to mean logarithms indicated by crosses.

Table 2. Chemical Characteristics of Waters Used in the Experiments.

Source of Water	Calcium (ppm)	Magnesium (ppm)	Sodium (ppm)	Potassium (ppm)	Total Alkalinity (ppm, $CaCO_3$)	Sulfate (ppm)	Chloride (ppm)	Silica (ppm)	p^H	Specific Conductance (micromhos at 18° C)
Silver River	11	2	0.7	0.7	34	2	2.8	4.9	7.7	48.2
Lake Superior	14	2	1.3	0.5	45	1	3.5	2.2	7.7	78.9
Chocolay River ..	20	5	1.6	0.9	70	3	4.7	5.4	8.0	109.8
Bishop Lake	25	15	4.7	1.3	123	9	8.5	0.9	8.3	218.1
Douglas Lake	30	11	1.5	1.1	122	5	4.6	2.0	8.3	206.9
Lake Erie	30	4	6.6	1.2	92	14	25.3	1.0	8.1	227.9
Lake Michigan ...	32	9	4.2	1.1	118	21	10.3	2.5	8.3	233.8
Lancaster Lake ...	33	18	1.7	1.1	155	1	8.9	3.0	8.3	225.1
Ann Arbor Spring	36	3	21.0	2.9	104	85	95.0	13.0	8.2	497.7
Burt Lake	37	12	2.9	0.7	142	10	6.0	6.1	8.4	249.6
Trout River	47	17	1.4	1.4	185	0.5	6.0	5.0	8.5	285.2

Looking at some of the other ions, note that the spring water is unusually high in Na^+, K^+, $SO_4^=$, and Cl^-. If any of these ions is important, its effect should be disclosed by a discrepancy (for spring water) between the observed values of $C.F._{(Sr)}$ and the predicted $C.F._{(Sr)}$, which is given simply by the reciprocal of $Ca_{(env)}$ times a proportionality constant characteristic of the species. It might be added that Lancaster Lake is a highly colored water and probably contains a high concentration of dissolved organic matter.

The results of a double-tracer experiment using these natural waters from diverse sources (Fig. 5) show greater variance than the preceding experiment, but the observed values of $C.F._{(Sr)}$ still fall reasonably close to the $C.F._{(Sr)}$ predicted by the OR relationship indicated by the straight line (solid) with slope of minus one on a double logarithmic plot. Calculated regression lines would fit the data only slightly better than do those shown in Fig. 5. These results, therefore, add credibility to the belief that, for a given species, the OR is a constant. Actually, the OR did exhibit a slight increase with decreasing $Ca_{(env)}$ (Fig. 6). The change was not great enough, however, to cause the observed values of $C.F._{(Sr)}$ to diverge seriously from the reciprocal curve (Fig. 5).

By plotting concentration factors for both strontium and calcium, rather than their absolute concentrations, the "discrimination" against strontium relative to calcium is graphically illustrated (Fig. 5). These results show that calcium is concentrated to a much greater degree than is strontium. The OR is also defined by the ratio: $C.F._{(Sr)}/C.F._{(Ca)}$. The average OR in this experiment, therefore, is given by the ratio of the respective proportionality constants of the two curves; hence: $4.6/8.0 = 0.58$.

Acknowledgments

Miss Paula A. Nessle assisted in the experimental work and collected water samples from the lakes in Cheboygan County.

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SURFACE CALCIUM-CHLORINITY RELATIONSHIPS

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SURFACE CALCIUM-CHLORINITY RELATIONSHIPS

Billie Z. May

Concentrations of calcium ions directly affect the existence and distribution of aquatic organisms (De Sousa, 1954; Borg, 1931). This element plays a significant role in cellular synthesis of phytoplankton (Robertson, 1941). Calcium studies are a prominent part of numerous ecological surveys of marine, brackish, and freshwater ecosystems (Remane and Schlieper, 1958; Vinogradov 1953).

Literature pertaining to calcium in the waters of the west coast of Florida is scarce. The only available data are those of Dragovich, Finucane, Kelly, and May (1963). Data forming the base for this research were collected as part of the red-tide and estuarine ecological investigations conducted by the Bureau of Commercial Fisheries. The objective of this study was to develop formulae for the rapid determination of calcium in surface waters of Tampa Bay and the adjacent neritic area.

Materials and Methods

The investigation of the calcium content of surface waters was initiated in April 1960 at stations already being systematically surveyed for other chemical, physical, and biological parameters (Dragovich *et al.*, 1963). Duration of the sampling period was 16 months, continuing through July 1961. No samples were taken in April 1961. Surface samples were collected monthly at all stations (fig. 1). At stations 1 through 20, sampling occurred within one hour of high tide. Stations 21 through 25 were sampled regardless of tidal stage.

Water samples for calcium and chlorinity analysis were collected with modified Van Dorn sampling bottles (Van Dorn, 1957).

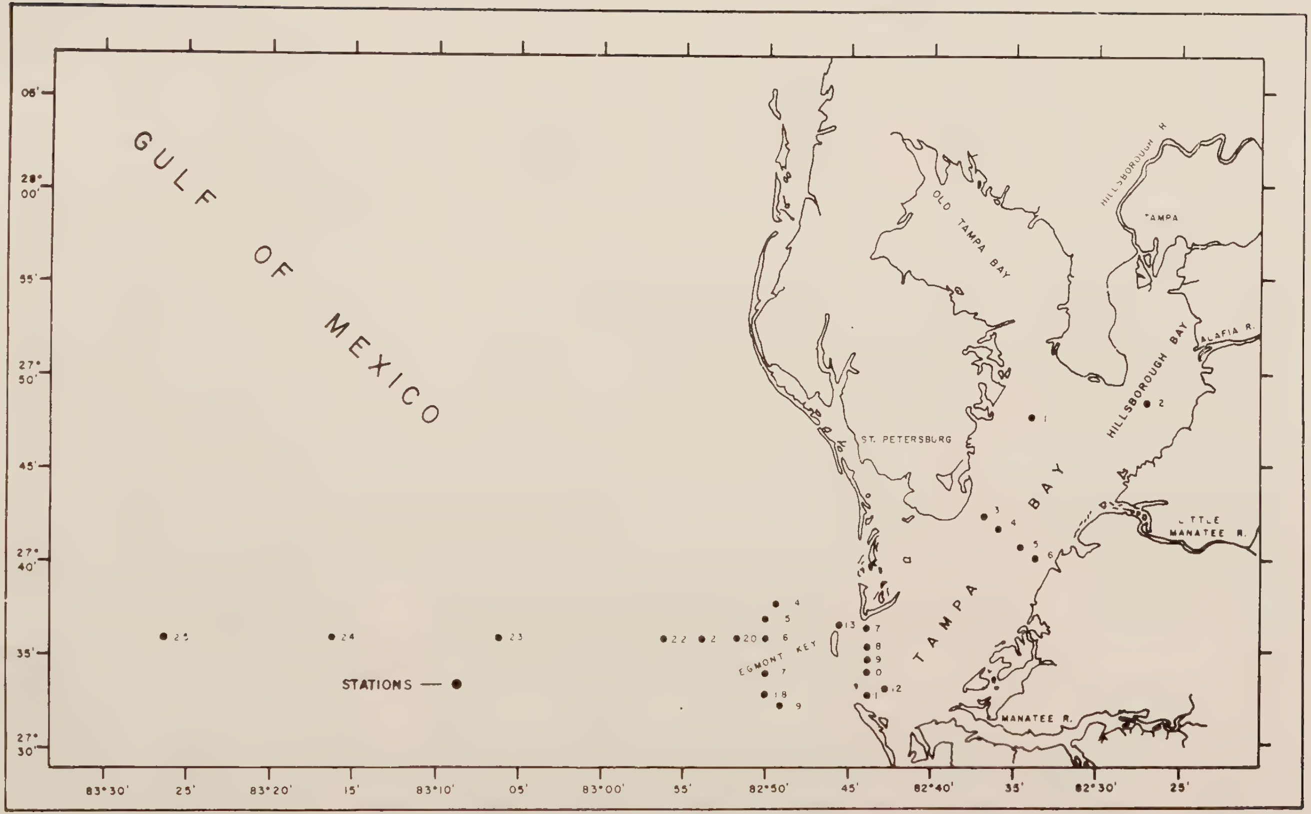

Fig. 1. Tampa Bay area showing station locations.

The aliquots for calcium were dispensed into 250 ml reagent bottles and capped with ground glass stoppers. Samples for chlorinity measurements were dispensed into 4-ounce prescription bottles and closed with standard lined-plastic caps.

The large number of water samples to be analyzed in the laboratory necessitated selection of a fast, dependable method for determining calcium content in sea water. The classic method is to precipitate calcium as the oxalate and ignite the precipitate to the oxide (Thompson and Wright, 1930; Matida, 1950). This method was considered too time-consuming to lend itself well to estuarine investigations. The same objection applied to the calcium oxalate precipitation method which involves dissolution of the oxalate in sulfuric acid and titration of the oxalic acid with potassium permanganate (Kirk and Moberg, 1933; Gripenberg, 1937). Direct titration of sea water with disodium ethylene-diaminetetracetate (EDTA) is a method which embodies rapidity, east of manipulation, and negligible error. This method was selected for the calcium determinations in the present study. The error resulting from the complexometric titration is negligible because of the weak iron content of sea water (less than 1 ppm) and trace amounts of aluminum and other elements.

In the EDTA titration of sea water for calcium, the procedure was as follows: An aliquot of 100 ml was adjusted with sodium hydroxide to a pH slightly greater than 12.0. A suitable amount (0.6 ml) of a 0.1 per cent solution of murexide (ammonium purpurate) was added as an indicator and the solution titrated with 0.1 molar EDTA until the indicator turned blue-violet. Other ions present do not interfere in this procedure. The Ca^{+2} concentration was then calculated in milligram-atoms per liter, assuming that, stoichiometrically, 1 ml of the reagent was equivalent to 4.008 mg. of calcium. Calcium values in this study were reported in milligrams per kilogram of sea water.

Chlorinity measurements were made according to a modified version of the Knudsen method (Oxner, 1920) with a standard silver nitrate titration. Replacement of the Knudsen burette by an automatic Schellbach burette facilitated the evaluation of low level chlorinities. Other modifications in the equipment and procedure are described as follows: A 15 ml portion of the sample was withdrawn with an automatic pipette and discharged into a 100 ml Berzelius beaker. The aliquot was placed on a magnetic stirrer and

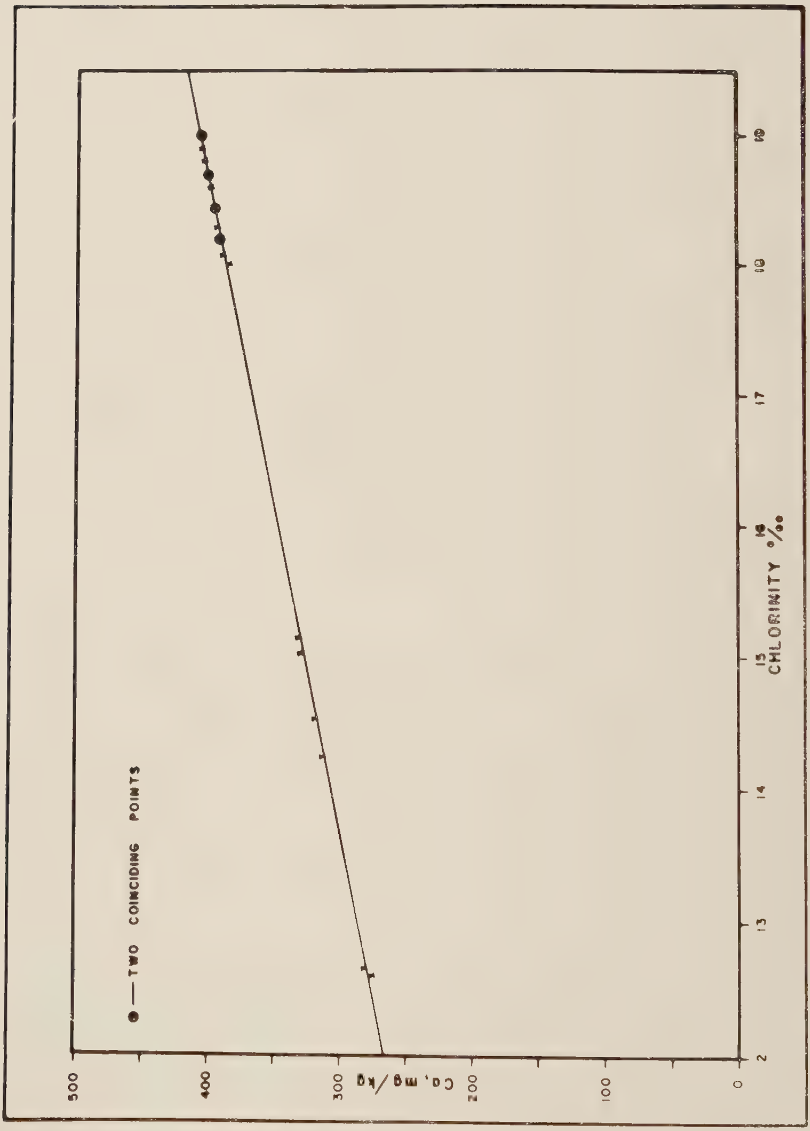

Fig. 2. The relation between the monthly means of calcium and chlorinity values for the inshore area.

an adequate quantity (1 ml) of an 8 per cent solution of potassium chromate added as an indicator. The aliquot was titrated with silver nitrate solution subsequent to the adjustment of the titer so as to be approximately equivalent in double milliliters (2 ml per 1 o/oo Cl) to the chlorinity of I.A.P.O. standard sea water (19.376 o/oo Cl). The end point was taken as the change in color from yellow to faint red which persisted for 30 seconds. The chlorinity was corrected by use of correction values in Knudsen's Hydrographical Tables (Knudsen, 1901).

RESULTS

Stations 1 through 20 were considered as inshore area, while stations 21 through 25 were designated as offshore (fig. 1). This classification is based upon calcium and salinity variations in both areas. In inshore and offshore areas the salinity varied 138 per cent and 2 per cent, respectively. The calcium variation was of similar magnitude in that the inshore variation was 129 per cent and the offshore 13 per cent.

The means of the fifteen calcium values for each station were plotted against the means of the chlorinities for the inshore area (fig. 2). The analogous values for offshore water were treated similarly (fig. 3). A straight line relationship was found to exist for the range of values encountered.

An equation for each straight line was computed by the method of least squares. Individual values were used in the calculations rather than the means shown in the figures. In the inshore area chlorinity and calcium values varied from 7.73 to 19.81 o/oo and from 173.2 to 426.0 mg/kg, respectively. The range of chlorinity and calcium in the offshore area was 18.06 to 20.23 o/oo and 382.8 to 434.1 mg/kg, respectively. For inshore waters the derived formula (equation 1) was:

$$\text{Ca (g/kg)} = 0.0154 + 0.0207 \text{ Cl (o/oo)}.$$

The formula (equation 2) for the offshore area was:

$$\text{Ca (g/kg)} = 0.0004 + 0.02137 \text{ Cl (o/oo)}.$$

Both formulae were tested for accuracy by comparing titrated calcium values with derived values from 52 sea water samples. These samples were collected from locations originating at the mouths

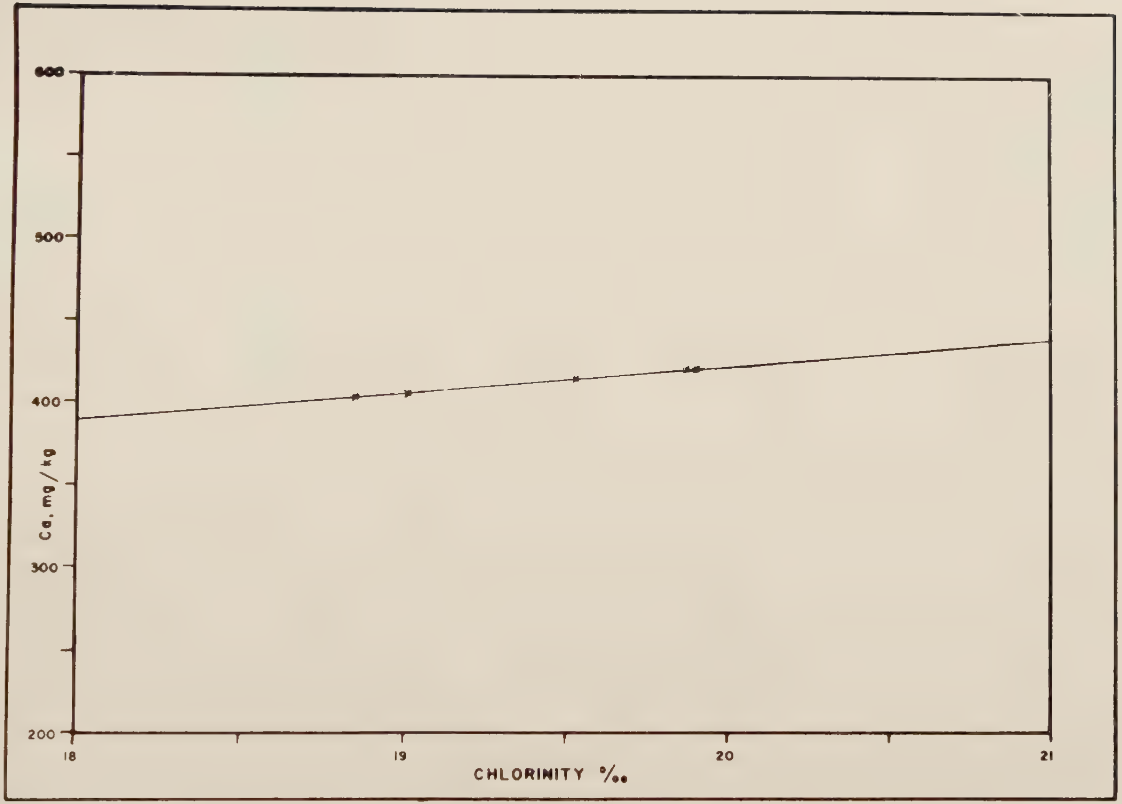

Fig. 3. The relation between the monthly means of calcium and chlorinity values for the offshore area.

TABLE 1

Standard and average deviation between calculated and analytical values of calcium

A. Inshore Formula

	(mg/kg)				(mg/kg)		
Sample	Anal.	Formula	Diff.	Sample	Anal.	Formula	Diff.
1	246.7	240.6	—6.1	21	384.5	382.0	—2.5
2	249.9	241.7	—8.2	22	379.6	377.6	—2.0
3	251.1	242.7	—8.4	23	361.2	354.7	—6.5
4	251.5	244.8	—6.7	24	359.0	349.7	—9.3
5	251.8	246.0	—5.8	25	392.2	388.8	—3.4
6	250.3	243.9	—6.4	26	375.1	383.6	+8.5
7	252.6	245.4	—7.2	27	319.3	313.7	—5.6
8	251.5	244.8	—6.7	28	387.9	387.6	—0.3
9	248.3	244.8	—3.5	29	345.1	340.8	—4.3
10	286.3	288.4	+2.1	30	288.2	273.7	—14.5
11	253.3	251.0	—2.3	31	383.8	381.8	—2.0
12	245.2	243.7	—1.5	32	383.4	381.6	—1.8
13	224.2	217.0	—7.2	33	392.5	391.1	—1.4
14	203.5	196.1	—7.4	34	393.3	390.5	—2.8
15	322.2	332.5	+10.3	35	385.3	403.9	+18.6
16	285.9	299.0	+13.1	36	362.4	373.3	+10.9
17	302.4	307.9	—5.5	37	322.0	327.6	+4.7
18	280.8	267.3	—13.5	38	283.2	285.7	+2.5
19	290.2	271.0	—19.2	39	389.5	398.7	—9.2
20	382.4	378.3	—4.1	40	368.0	378.2	—10.2

Average Deviation = 6.7 mg/kg or 2.1% error
Standard Deviation = 8.0 mg/kg

B. Offshore Formula

1	398.6	399.4	+0.8	7	395.0	413.3	+18.3
2	398.6	396.5	—2.1	8	408.5	419.9	+11.4
3	401.9	399.4	—2.5	9	406.2	404.5	+1.7
4	407.0	406.0	—1.0	10	402.7	404.7	—2.0
5	416.2	419.9	+3.7	11	412.2	414.1	—1.9
6	403.9	404.8	+0.9	12	406.9	409.2	—2.3

Average Deviation = 4.0 mg/kg or 1.0% error
Standard Deviation = 6.9 mg/kg

of Old Tampa and Hillsborough Bays to a distance of 40 miles offshore. The calcium levels in these samples were determined analytically by titration and also by applying the applicable Ca/Cl formula, subsequent to titration of the chlorinity. The average deviation of calculated values from analytical values for the inshore area was 6.7 mg/kg (table 1). This represented an average error of 2.1 per cent in that area. The standard deviation amounted to 8.0 mg/kg. For the offshore area, the average deviation was 4.0 mg/kg or 1.0 per cent error. The standard deviation was 6.9 mg/kg.

DISCUSSION

Noticeable differences in the Ca/Cl ratio have been observed in various marine areas of the world (Sverdrup, Johnson, and Fleming, 1942). No agreement was found between our Ca/Cl ratios observed in the inshore area and those of oceanic waters (Kirk and Moberg, 1933; Thompson and Wright, 1930; Chow and Thompson, 1955; Carpenter, 1957).

Equating $Cl = 0$ in equation 1, an intercept value of 0.0154 is found which indicates that the offshore waters entering Tampa Bay are diluted with fresh water containing 15.4 milligrams of calcium per kilogram of water. The surface waters of the immediate offshore area approach a direct ratio closely since in this instance the intercept value in equation 2 is 0.0004.

By utilizing these two formulae for the areas specified, calcium values may now be determined without recourse to chemical analysis. The only analytical requirement is an accurate measurement of chlorinity which can be obtained with a conductivity cell. This procedure for the determination of calcium presents a rapid and convenient method. The reduction in laboratory expenditures and time is of practical significance.

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Reproduction among deep-sea fishes

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Abstract—Known and suspected mechanisms used by the various groups of deep-sea fishes to locate mates and otherwise assure fertilization of gametes, and those associated with the production, development and protection of young are reviewed. These in turn are related to the reproductive demands made by the deep-sea environment.

INTRODUCTION

ABYSSAL fishes, like other organisms, must reproduce to survive and must adapt their reproductive habits to their environment. The deep-sea environment imposes certain problems not encountered in shoaler waters. Among them are the absence of solar light, of seasonal change, and of primary organic productivity. We propose to explore here the ways in which deep-sea fishes accommodate reproductively to this environment and to review the methods by which they solve certain biological problems common to all vertebrates. These problems include mate location and fertilization and survival of the eggs and larvae, i.e. the part of the life cycle between gonad maturity and the time at which the young is ecologically an adult. We arbitrarily take deep-sea *species* to be those which live as adults below 2000 m, either on the bottom or in midwater, and use as our principal list of this fauna that by MARION GREY (1956). It will become clear that information on reproduction, eggs, and larvae of most members of this fauna is fragmentary. We consider deep-sea *groups* to be those which have representatives which live below 2000 m. In the many instances in which reproductive information on the deep-sea forms is lacking, we have extrapolated from knowledge of those living above the 2000-m contour. We have tried to separate fact from conjecture, both in reviewing source material and in preparing our summaries, but unfortunately the conjectoral aspects of reproduction below 2000 m predominate. We will first summarize our reproductive knowledge of the major deep-sea groups and will close with comments of a more general nature.

Class **Chondrichthyes**

The sharks, skates, rays and chimaeras are represented below 2000 m by about fifteen species, many of which have broad bathymetric distributions centered above this contour (*e.g.*, *Raja bathyphyla*, 676–2173 m; *Centroscymnus coelolepis*, 330 to below 2000 m; *Harriotta raleighana*, 530–2603 m). In all members of the class,

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pigmented sac beneath the upper part of the cleithrum (the shoulder organ) from which these animals can eject a luminous fluid at will (Nicol, 1958 : 726), but no reproductive function can yet be attributed to this ability. The presence of large eyes and well developed and varied light organs, however, suggests that visual cues assist in mate location among the Searsiidae.

The Alepocephalidae have no shoulder organ and few of the many genera (*Xenodermichthys*, *Photostylus*, and perhaps *Anomalopterus* and others) have structures that are said to be luminous. Although it must be remembered that luminescence is not restricted to definite organs but may derive from tissue which even by microscopic examination may not be recognized as the source, the lack of well developed light organs in most alepocephalids indicates that contact between sexes is established by other means.

We have here two closely-related families : the Searsiidae, living in the three-dimensional bathypelagic environment; and the Alepocephalidae, most of which are benthonic. The former perhaps mildly gregarious, have probably evolved a system of sexual communication based on light production and reception, as have other successful bathypelagics such as the Isospondyli and Iniomi. The latter, benthic species which are non-luminous as are most of their unrelated neighbors, may rely more strongly on shoaling or perhaps migration for reproductive contact.

Gonads : other than repeated reports of large but few ovarian eggs—conditions conducive to the bathypelagic near-bottom young probable among alepocephalids —little information is available.

A suggestive observation is recorded by Vaillant (1888), who found that the ovary of a 164 mm alepocephalid, *Leptoderma macrops*, contained eggs of two size groups, about two dozen large eggs of up to 3 mm in diameter and numerous small eggs smaller than 1 mm. Some information has been obtained through a hurried examination of the yet unidentified adult alepocephalids from the *Galathea*. Of the 23 specimens examined, the smallest five, 14–22 cm standard length, are immature and sex cannot be determined without histological preparation. Eleven of the remaining 14 specimens, 22–43 cm long, were females. (The small number of specimens representing different species does not allow conclusions regarding sex ratio or the apparent larger size of females.) The eleven females contained ripening eggs of individual maximum diameters of 1·6–3·2 mm. None were ripe. Five specifically identical specimens from the same haul made on the bottom at 900–1000 m were in the same stage of maturity, each having ripening eggs of 1·6-1·8 mm, indicating a common spawning time.

The ovary of the specimen with largest eggs, a 34-cm long *Bathytroctes* sp. from a bottom haul at 3390 m in the Mozambique Channel, was examined in more detail. The main content of the ovary consisted of 488 ripening spherical eggs, 2·5–3·2 mm diameter (av. 2·8), filled with orange-colored yolk. Among them were about fifty smaller, pale-yellow, irregularly shaped eggs of 1·0-2·8 mm (av. 2·2), which may be eggs from the same batch but retarded or completely checked in development; and two large eggs, 4·0 and 5·2 mm, of similar appearance and no doubt residual from the former batch. Finally, the wall of the ovary contained numerous young developmental stages of eggs, mostly betwen 0·1 and 0·6 mm which probably represent the next developing batch. Except for the various stages of maturity, the ovaries of the other specimens looked very similar, giving the impression that each would spawn between about 300 and less than 1000 eggs at a time, that the ripe eggs would be large (probably 4·5 mm diameter or more) and rich in yolk, and that the developmental stages of eggs for two spawnings are simultaneously present.

All of the Searsiidae examined were immature except for a specimen of a *Barbantus* 12·5 cm long which contained a few eggs, 0·7–0·8 diameter, in the badly preserved ovary.

No indication of hermaphroditism or of viviparity has been observed in Searsiidae and Alepocephalidae.

Larval development : a number of small juveniles and a few larval stages of these two families have been described*.

BEEBE (1933) has given detailed descriptions of larvae 9·5–14 mm in standard length which he refers to *Bathytroctes drakei* and *B. rostratus*. Larvae and juveniles of the latter species have also been described and figured by MURRAY and HJORT (1912, pl. 9). These *Bathytroctes* bear the shoulder organ diagnostic of the Searsiidae but according to PARR (1960) identification of specimens shorter than 20–30 mm is not possible even to genus. Those specimens in Beebe's material which lacked the shoulder organ were probably alepocephalids. All of these larvae have large yolk sacs, small heads of very embryonic appearance, large brains, small eyes, feeble jaws, and lightly pigmented bodies. Clearly these young shorter than abcut 12 mm depend solely on the yolk for nourishment. While the yolk is being resorbed, the head, eyes, jaws, and teeth develop rapidly and the darkly pigmented specimens 12–15 mm long which Beebe terms postlarvae have an appearance which in most other fishes would be called adolescent.

In contrast to the situation normal to most bathypelagic fishes, young alepocephalids and searsiids occur in relatively deep water. MURRAY and HJORT (1912 : 743) record a center of abundance for young '*Alepocephalus*' between 500 and 1000 m. Of the 102 larval and postlarval specimens studied by BEEBE (1933), most came from depths between 600 and 900 fm (1100–1650 m), and there was no indication of seasonal variation in abundance. The numerous larval and juvenile alepocephalids and searsiids caught by *Dana* have not yet been studied, but about 90% of these 500 specimens were caught in nets fished at depths greater than 1000 m.

The available data thus suggest that the Searsiidae are pelagic and the Alepocephalidae pelagic and benthic, that species and perhaps mate location in the Searsiidae is mainly visual and is based on luminescence, that at least some alepocephalids tend to be gregarious near the sea bottom, that the members of both families are dioecious and oviparous, producing a relatively small number of large eggs, that larvae of both families are bathy- and possibly abysso-pelagic. have large yolk sacs at hatching and develop very directly into the adolescent stages.

Order **Iniomi**

This order is represented by two natural phyletic lines : the alepisauroids, the species of which are wholly pelagic and bathypelagic; and the myctophoids, represented by the pelagic families Myctophidae, Neoscopelidae, and Scopelosauridae, the estuarine and coastal Harpodontidae, and an array of benthonic

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*The two larvae described by ROULE and ANGEL (1930, pl. 1, fig. 2–3) as *Talismania* sp. are neither alepocephalids nor searsiids.

families ranging in depth distribution from the intertidal zone to the abyssal plain. Few pelagic Iniomi are known positively to occur below 2000 m, but the benthic myctophoid families Bathypteroidae, Bathysauridae, and Ipnopidae are chiefly distributed below this depth.

Visual location of mates through the development of external sex specific characters, such as the median caudal photophores of the lantern fishes and differences in fin length in aulopids, is restricted to coastal and pelagic groups and appears to be completely lacking among the alepisauroids. Many of the alepisauroids and benthic myctophoids, however, are known to be regularly hermaphroditic. Published accounts (Mead, 1960; Gibbs, 1960; Gosline, Marshall and Mead, in press) note monoecious species of Chlorophthalmidae, Bathypteroidea, Alepisauridae, and Paralepididae--a list to which we may now add the Ipnopidae* and the Evermannellidae†. These are in no way teratological, and while the genetic advantages of cross-fertilization would suggest that this should be considered the normal procedure pending strong evidence to the contrary, the ability to self-fertilize may be present, and may provide the ' insurance ' permitting reproduction in the absence of a mate—an absence possibly common in low density abyssal populations. It should be noted, however, that one such monoecious group, the Chlorophthalmidae, is chiefly composed of species which are quite abundant on suitable continental shelf substrates.

Young representing all pelagic iniomous families are known from the upper layers of the oceans, as are those of the benthonic Aulopidae and Synodontidae. Young of the typical Chlorophthalmidae, the adults of which live at depths rarely exceeding 800 m, are known from the Mediterranean (Tåning, 1918; Sanzo, 1915); a few unidentified specimens in the *Dana* collections; and from a series of eight individuals taken off New England in a net fished at 85 fm (155 m) in water 800–1000 fm (1463–1829 m) deep‡. These records are few relative to the abundance of the group but the evidence suggests epipelagic development. Of the benthonic inioms from deeper water, only one young, attributed to *Bathypterois*, has been reported (Roule and Angel, 1921 : 3), but this fish is probably a stomiatoid of the order Isospondyli (see discussion, Mead, in press). There is thus little direct indication of epipelagic development in abyssal-benthic iniomous species. Bearing on the question of possible larval habitat is fecundity. In contrast to the millions of eggs generated annually by an adult haddock, the tens of thousands of larvae spawned by the ovoviparous redfish (*Sebastes*), a 139 mm *Bathypterois* (*Bathypterois*) *quadrifilis* from 1200 m contained but 4500 eggs and a 106-mm *Ipnops murrayi* from about 2000 m only 900§.

Even given the possibility of repeated spawnings within a year, the small number of eggs and the hazards of a journey for eggs and larvae ascending and descending through a water column a mile high make epipelagic development seem improbable.

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*From the sectioned gonad of a 106 mm *Ipnops murrayi* taken by the U.S. Bureau of Commercial Fisheries research vessel *Oregon* at Sta. 2577, 27°48′N, 88°45′W; July 30, 1959; 850–1100 fm (1554–2012 m); bottom trawl.

†From the sectioned gonad of a 105 mm *Coccorella atrata* taken at 1500 m during a ' shakedown ' cruise of the research vessel *Anton Bruun*, 39°10′N, 71°52′W; January 9, 1963. We are indebted to Donald W. Bourne for these histological preparations.

‡U.S. Bureau of Commercial Fisheries exploratory vessel *Delaware*; Oct. 14, 1961; Cruise 61–18; Stn. 4; 41°38′N, 65°41·5′W to 41°24·5′N, 65°44′W; 85-ft pelagic trawl.

§*Bathypterois* (*Bathypterois*) *quadrifilis* from M/V *Oregon* Station 1426; Sept. 24, 1957; 29°07′N, 87°54′W; 600 fm (1097 m); bottom trawl. *Ipnops murrayi*, see data in footnote, p 573.

Available data thus suggest that the deep-sea Iniomi are monoecious, perhaps capable of self-fertilization in the absence of a mate, and that they produce a relatively small number of eggs which develop on or near the bottom.

Order **Apodes**

Of the two suborders of Apodes the nemichthyoids are exclusively pelagic deep-sea fishes, while most or all adult anguilloids are benthic. Several of the many families of the latter suborder are confined to, or have representatives in, the deep sea.

Representatives of all three families of nemichthyoids, the Nemichthyidae, Serrivomeridae, and Cyemidae, are known from depths of more than 2000 m, and species of *Serrivomer*, *Avocettina*, and the only known cyemid, *Cyema atrum*, seem to have their main distribution in abyssal regions. According to MARION GREY (1956), representatives of five anguilloid families reach abyssal depths, and several other benthic eels of this suborder probably do so. Among these only some species of *Synaphobranchus* can, with reasonable certainty, be included in the abyssal fauna with distribution centres below 2000 m. It should be remembered that eels in general are most adept at avoiding or escaping from slow-moving fishing gear and that the existing collections of adult deep-sea eels are remarkably small compared with those of oceanic leptocephali, most of which are unidentified and may include several species the adults of which are unknown.

Mate location : one of the factors that might reduce the problem of mate location among the deep-sea Apodes is a tendency to form relatively dense populations. Not only the benthic species, especially *Synaphobranchus*, but the pelagic nemichthyids as well are often represented by several specimens per haul. This is illustrated by the *Dana* records reported by ROULE and BERTIN (1929) and BERTIN (1937). In spite of numerous negative stations within the respective areas of distribution, a remarkably small proportion of the adolescent and adult specimens were caught singly. Only twenty of 128 *Serrivomer sector*, nineteen of 114 *Nemichthys scolopeus*, four of 34 *Avocettina infans*, and seven of the fifteen *Cyema atrum* were caught singly.

Another important factor is the tendency for eels to spawn in selected areas and during particular seasons. This has been shown in a number of North Atlantic deep-sea species, for example in the nemichthyids by ROULE and BERTIN (1929), SCHMIDT (1930), and BAUCHOT (1959); in *Nessorhamphosus* by SCHMIDT (1930); and in *Synaphobranchus* by BRUUN (1937). The youngest larvae of most of these species are restricted to, or most abundant in, the Sargasso area while the older leptocephali and adults are much more widely distributed. Consequently, relatively long spawning migrations must be assumed. The occurrence of young larvae show that the duration of the spawning season of each species may be a few months, varying in time of year from species to species.

Light and sense organs : eyes and lateral line organs are especially well developed in the pelagic Apodes, and in these as well as in the benthic deep-sea eels the olfactory organs are large. Experiments with *Anguilla* have shown that their sense of smell is extremely sensitive, and this sense probably plays an important role in the biology of their deep-sea relatives. Besides being of great value in food location, olfaction may aid in species recognition. Luminescence has not been observed in any eel.

Development : we have little relevant information on the development of the gonads in deep water eels. BEEBE (1935 : 19) reported that a ' ripe ' *Derichthys serpentinus* contained eggs of two sizes, the larger *ca.* 0·75 mm diameter and numbering about 4100, the smaller at most 0·14 mm across and in about equal numbers. Others, such as ALCOCK (1899 : 203,206) in *Xenomystax* and *Promyllantor*, PARR (1932) in *Platuronides ophiocephalus*, and CASTLE (1961 : 11) in *Avocettina* (or *Borodinula*) *infans*, have reported ' ripe ' individuals, but as ripeness is relative these observations are of limited value here.

A few samples of the ovarian eggs of *Synaphobranchus* were taken from the *Galathea* material. The five specimens sampled were of similar size (60–72 cm) and came from a single haul made at a depth of about 2800 m off Durban. Although *Synaphobranchus*, as shown by the occurrence of young leptocephali, has a fixed spawning season, these specimens were in different stages of maturity. Two had large eggs ranging from 1·7–2·2 mm, the third contained ova 1·0–1·3 mm dia. Between these larger eggs all three samples contained yolkless small developing eggs of 0·2–0·5 mm and in the two remaining samples such small eggs were the only content. Some large nemichthyids from the *Dana* and *Galathea* expeditions were examined, but all were immature.

At least in certain regions pelagic eel eggs are quite common in oceanic plankton. They are characterized *inter alia* by their very large perivitelline space. On the *Dana* expeditions a number of different types were distinguished by means of size, oil globules, pigmentation of embryos, etc. and some were identified after hatching. Most types were 2·0–2·6 mm dia. but some unidentified types reached about 4 mm. Greatest numbers were caught less than 200 m below the surface, but due to the use of open nets the lower limit of their vertical distribution is uncertain. The eggs of *Synaphobranchus* and nemichthyids are still unknown but their leptocephali have been recorded in great numbers. They are all epipelagic. As shown by BRUUN (1937) the *Synaphobranchus* leptocephali which have telescopic eyes avoid the uppermost surface layers and have their center of distribution between 100 and 250 m. According to ROULE and BERTIN (1929) and BAUCHOT (1959) the nemichthyid leptocephali of the genera *Nemichthys* and *Serrivomer* which have normally developed eyes are most numerous between the surface and 100 m. Most larvae of *Cyema atrum*, which as an adult lives in especially deep water, are caught between 100 and 200 m.

Because of the existence of a spawning season it has been possible to trace the growth of the leptocephali of several species and to estimate the duration of their development prior to metamorphosis. BRUUN (1937) found the length of the pelagic larval life of *Synaphobranchus kaupi* to be about 18–22 months, and BERTIN (1937) estimated the larval life of *Cyema atrum* to be about two years. According to BAUCHOT (1959) the *Serrivomer* larvae *Leptocephalus lanceolatus* and *L. lanceolatoides* metamorphose at an age greater than ten months.

During their long leptocephalus stage the eels grow to a considerable size prior to metamorphosis, compared to most other teleosts. In the deep-sea species here considered these lengths are as follows : *Synaphobranchus* about 13 cm, *Serrivomer* 5–7 cm, *Cyema* 8–10 cm, and the slender, long-tailed *Nemichthys* about 25 cm. Some unidentified oceanic leptocephalids reach even larger sizes. The record is an undescribed giant leptocephalus of about 180 cm caught by the *Dana* (BERTIN, 1954). Another of 89·3 mm was described and christened by CASTLE (1959) who considered it to be a normal but large larva, not a pathologically neotenic individual. No doubt it is an advantage to some species to start their deep-sea life at a relatively large size.

The main information on reproduction in abyssal Apodes may be summed up as follows : in both the benthic and pelagic species the problem of mate location is reduced by a tendency to shoal and to spawn at certain times and in certain areas. No luminescence or other special adaptation to species recognition has been reported. The sense of smell seems of major importance. The deep-sea species are dioeceous and oviparous, as are other eels. All known eggs are epipelagic.

The epipelagic larval stage is of long duration, and the leptocephali reach a considerable size before, in metamorphosing stages, they descend to the depths.

Order **Lyomeri**

Representatives of all the three genera of this order of pelagic oceanic fishes have been caught in nets fishing in depths greater than 2000 m, and all species can be expected at such depths. However, the known number of adults of the genera *Saccopharynx* and *Monognathus* is too small to determine the main vertical distribution. The only known species of *Eurypharynx*, *E. pelecanoides*, is relatively common and adult specimens have been caught at depths from about 250 to more than 7000 m with the center of distribution at about 2000 m.

Of fifty-nine adult *Eurypharynx* collected by the *Dana* expeditions and listed by BERTIN (1934) only fourteen were caught singly, a non-random distribution perhaps useful in mate location.

Both in *Eurypharynx* and at least one of the species of *Saccopharynx* the distal part of the slender tail carries a light organ. Eyes and olfactory organs are normally developed and the lateral line organs are large and numerous.

In the one species studied (' *Gastrostomus bairdi* ' = *Eurypharynx pelecanoides*), the sexes are separate and the ovary is arranged in a peculiar leaf-like pattern along the oviduct (NUSBAUM-HILAROWICZ, 1923 : 71–74). GILL and RYDER (1884) found in *Eurypharynx* large ovaries with many small eggs about 0·7 mm dia. The pelagic eggs have not been identified but larvae referable to the Lyomeri are not rare in collections from oceanic expeditions. Like the Apodes, the Lyomeri pass through a leptocephalus stage. Two types of larval gulper eels have been described : *Leptocephalus latissimus* SCHMIDT 1912 and *L. pseudolatissimius* BERTIN 1936. ORTON (1963) agrees with BERTIN that the latter and most common type represent *Eurypharynx* and assigns the other to *Saccopharynx* with some uncertainty. LEA (1913 : 43–46) has described a specimen of *E. pelecanoides* (' *Leptocephalus Gastrostomus Bairdi* ') in an advanced stage of metamorphosis.

The majority of the specimens of both types have been caught at 100–200 m, i.e., in the lower part of the epipelagic layer.

From the size distribution of about forty *L. pseudolatissimus* from the western Atlantic, BERTIN (1938) estimated that the larval life has a duration of more than two years. Compared with deep-sea eels the size at metamorphosis is small, being only 30–35 mm in *L. pseudolatissimus*. However, as their gape is enormously developed even at this stage, they can swallow relatively large food items from the start of their deep-sea life.

Order **Anacanthini**

Families *Moridae and Gadidae*

Three species of Moridae have been recorded from below 2000 m. One of these, *Laemonema melanurum*, was taken in midwater, probably from above 2000 m. The second species, *Lepidion lepidion* from the North Atlantic, is commonest at 650–1000 m (GREY, 1956). Although there is a considerable literature on this species, little is known of its reproduction. According to SAEMUNDSSON (1926), fishes of the genus *Gargilius* are the pelagic young of *Haloporphyrus eques* (a synonym of *Lepidion lepidion*). These young stages are known from several localities in the North Atlantic (SCHMIDT, 1906; KOEFOED, 1953; SAEMUNDSSON, 1949), including at least one above 200 m. *Lotella maxillaris* BEAN 1884 from south of Georges Bank is identical with *Gargilius*, and *Hypsirhynchus hepaticus* (FACCIOLÁ, 1884) (although not the material identified as this species by GIACOMO, 1936 and D'ANCONA, 1933) is probably also the same species.

The third abyssal morid is *Antimora rostrata*, which is distributed around the world at depths of 403–2904 m (GREY, 1956). Although *Antimora* is not a rare fish nothing is known of its reproduction. Both *Lepidion* and *Antimora* have at times been collected in some numbers, indicating that they must form aggregations.

Some morids of the continental shelf and slopes have photogenic organs associated with the urogenital regions, and luminescence probably plays some role in the reproductive process. No deep abyssal morid is known to produce light.

A single species of Gadidae, *Gaidropsarus ensis* is found below 2000 m. Although nothing is known of its reproductive habits, closely related species from lesser depths have pelagic eggs and young (SVETOVIDOV, 1948).

Family *Macrouridae*

There is little direct evidence of mating habits or larval development of the abyssal species of macrourids, some 55 in number. MARSHALL (1962 : 56) has noted the development of sound-producing swimbladder structures in the males but not in the females of certain species, observations suggesting sexual communication through sound production and reception. The photogenic organs associated with the urogenital region in some species also may be of use in mate location. The reproductive systems are in no way unusual. The sexes are separate, some are externally dimorphic (*e.g.* GILBERT and HUBBS, 1920 : 370), and the life span of the few deep-sea forms studied is not excessive (a maximum of eight or nine years in the four abyssal species of *Coryphaenoides* studied by KULIKOVA, 1959 : 286). The number of maturing ovarian eggs is relatively large. In the shelf species *Coryphaenoides rupestris* and *Macrourus berglax* COLLETT (1903 : 71–78) reported counts of ovarian eggs ranging from 10,000–16,500 per individual, a range which includes the number found in a 325 mm specimen of *Cetonurus globiceps* from deeper water*.

The known distribution of eggs and larvae is obscured by the frequent misidentification of material reported in the early literature—literature fortunately reviewed by LUIGI SANZO in 1933. Referred by SANZO to the Serranidae, Lophiidae, or to the gonostromatid genus *Maurolicus*, or removed tentatively or finally from the Macrouridae without substitute designation, were the reports of EMERY (1879 : 588–589, and included figures subsequently reproduced by EHRENBAUM (1905–9 : 301–304), RAFFAELE (1888 : 65–66, pl. 5, figs. 7 and 7a), and ROULE and ANGEL (1921 : 7; 1930 : 111, pl. 6, fig. 145). SANZO (1933) has also noted the resemblance between the macrourid egg with its covering of polygonal facets to those of such forms as *Maurolicus*—comments which cloud the pertinence of figures and descriptions of presumed macrourid eggs such as those taken in the Skagerack (EHRENBAUM, 1905–9 : 303) and North Atlantic (HENSEN, 1887, pl. 4, fig. 20). Records of eggs or young unsupported by figures or descriptions, such as that of LO BIANCO (1904 : 165), are here discounted. The series of larval and juvenile *Steindachneria argentea* from the southern Caribbean reported by MEAD (1963) can be ignored in the present connection as this genus, whatever its relationships may be, lives in waters shallower than 240 fm (439 m) (SPRINGER and BULLIS, 1956). These eliminations leave information on the occurrence of macrourid eggs and larvae scarce indeed, and that for positively identified deep-sea forms wholly lacking. Pelagic adolescent macrourids of substantial lengths, usually greater than 50 mm and commonly over 100 mm, have been known from the Mediterranean since the description of *Krohnius filamentosus* COCCO, 1844 (e.g., COSTA, 1840–50; 1869 : 41, pl. 1, fig. 1; SMITT *et al.*, 1893–5 : 582), but the identity of the pertinent adult remains in doubt (SANZO, 1933 : 260). Similar pelagic '*Krohnius*'-stage adolescents have been reported from Messina (*Hymenocephalus italicus*, the adult name and relationship established by SANZO); *Ateleobrachium pterotum* from 300 fm off Kamchatka (GILBERT and BURKE, 1912 : 94, fig. 34; but see JOHNSEN, 1927 : 239–240); *Phalacromacrurus pantherinus* (MAUL and KOEFOED, 1950; MAUL, 1951 : 56; KOEFOED, 1953 : 7–8, pl. 1, fig. 1; and as 'young of *Macrurus*' by HJORT *in* MURRAY and HJORT, 1912 : 745, fig. 537) from *Michael Sars* catches and stomach contents of *Alepisaurus* taken off Madeira; and the series of *Armauer Hansen* specimens so admirably described and discussed by JOHNSEN (1927). Other examples, yet unreported but currently under study by N. B. MARSHALL, have been caught by the research vessels *Chain*, *Discovery*, and *Dana* and have doubtless been encountered during the oceanographic work of other vessels.

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*10,350 ova of similar size from a specimen taken at 860 m off Cuba by the Harvard–Havana Expedition.

The *Dana* cruises of 1920–22 and 1928–30 took 272 macrourids ranging in size from larval forms less than 10 mm long to individuals adult in size and appearance. These specimens are now under study by N. B. MARSHALL and will not yield significant information until the identity of the several species represented is complete. Depths of capture correspond to length-of-wire-out figures of 100–5000 m, and those most adult in form and coloration were caught at the deeper depths. The center of distribution is between depths corresponding to 400–800 m of wire, using the ratio between number of positive sets at any given depth to total number of sets at that depth as an index of relative abundance. Most individuals in these series are longer than 20 mm, and nearly all came from tows made at stations not far removed from the continental shelf. While the identity of these with their adults is beyond our grasp at the moment, the few mid-oceanic localities indicate that several may represent abyssal rather than coastal species (see also JOHNSEN's discussion, 1927 : 232–239). But it must also be remembered that some macrourids pelagic as adults are known and that the high-seas young may represent these species. If inshore captures and those made in areas of notable upwelling are excluded, three points of interest emerge : the relative scarcity of these adolescents; their bathypelagic nature, few having been taken in nets fished in layers shoaler than about 400 m and chiefly in waters much deeper; and their usually large size. Many of these '*Krohnius*' adolescents may be 'prejuveniles' in a sense similar to that of Hubbs (1958)—the young of benthic species which prolong their pelagic life and length beyond that normal to the group prior to seeking or finding the adult habitat.

Aside from reports of eggs and larvae from inshore localities such as the young stages of *Coelorhynchus coelorhynchus* (Costa) and *C. sclerorhynchus* (Valenciennes) (Sanzo, 1923 : 125; 1931 : 56, pl. 5; 1933 : 255 *et seq.* and pl. 16; Costa, 1869 : 41, pl. 1, fig. 1), macrourid larvae are unknown, although larvae are represented in the *Dana* collections as noted.

Two additional observations may be pertinent. First are those of Gilchrist (1905 : 135–137, pl. 6; 1921) on *Coelorhynchus fasciatus* from about 100 fm (183 m) and *C. parallelus* from 300–600 fm (549–1097 m), both off South Africa. The ovarian and free living eggs of macrourids contain a well developed oil globule and a polygonal surface marking, and in contrast to certain early works noted above, there is little doubt that Gilchrist's planktonic eggs are those of macrourids. While he found no planktonic eggs of *C. parallelus* in his *Pieter Faure* collections (and as ovarian eggs they could be distinguished by their relatively larger size, *ca.* 1·3 mm *cf.* 1·0–1·2 mm in *C. fasciatus*), those of *C. fasciatus* were taken in five plankton nets which were attached to the beam trawl fished on the *bottom* between 91 and 1000 fm (166–1829 m) but *not* in surface nets fished simultaneously. The evidence leads to conflicting conclusions, for these eggs were apparently caught in deep water near the bottom while the presence of an oil globule would suggest positive buoyancy and an epipelagic habitat for the eggs. Perhaps at depths these eggs are neutrally buoyant.

Finally we note the distributional findings of Parr (1946) in his study of western North Atlantic rattails; and of Gilbert and Hubbs (1920 : 371 *et. seq.*) on those from the western tropical Pacific. Both reports emphasize local endemism of species the adults of which live in basins at depths below that of the sill : the Gulf of Mexico in the first cited work the Sulu Sea in the latter. How can such autochthonous endemics arise and persist if their eggs and larvae develop there epipelagically, subject to dispersal into adjacent seas ? The regular occurrence of such epipelagic young seems doubtful.

This then is the evidence, much of it from within rather than beyond the 2000-m contour. Our guess is that many abyssal macrourids form spawning pairs of aggregations using sound for communication, and lay eggs which are externally fertilized, which normally develop bathypelagically or near the bottom, but which occasionally become displaced upward or seaward to develop into expatriate bathypelagic prejuveniles. The extension of Gilchrist's experiments with simultaneous midwater and near-bottom plankton sampling is much in order.

Order **Ophidiodei**

Family *Brotulidae*

This discussion is limited to the chiefly benthic ophidioids generally placed in the nominal family Brotulidae (Norman's manuscript draft synopsis, with modifications by Cohen[*]) and does not include the cusk eel group (family Ophidiidae, *sensu stricto*), the Pyramodontidae, the Carapidae, or the bathypelagic Aphyonidae

Brotulidae as thus restricted for the purposes of this discussion includes at least 175 species placed in about 60 genera. Radcliffe (1913) was the first to suggest that this assemblage (at least as much of it as he treated) could be separated, on the basis of type of reproduction, into an oviparous and a viviparous group. Norman (1939) also used type of reproduction, in combination with some morphological characters, to separate taxonomically two groups of Brotulidae.[†] However, he recognized those viviparous brotulids with caudal fin separate from the dorsal and anal fins as a subfamily distinct from Brotulidae with vertical fins confluent. We do not think this is a valid separation, and in the following discussion all viviparous brotulids (except the bathypelagic Aphyonidae, as noted above) are included within a single group. This group of viviparous species comprises about thirty genera and at least seventy species, perhaps two or three times this number. Of these seventy or more species, more than half dwell along the shore, in coral reefs, in midwater, and in fresh water. Approximately 35 species live on the continental shelf or below at depths beginning at approximately 150 m. Of these, only two are listed by Grey (1956) as deep abyssal.

If we now turn to the oviparous group of brotulids we encounter a group of about thirty genera containing roughly 100 species. These species are found only at depths of about 150 m or deeper, and no fewer than fifty of these species are listed by Grey (1956) as occurring in the deep abyss.

Thus we have viviparous brotulids living in a wide range of habitats but barely represented below 2000 m. Oviparous brotulids, on the other hand, are found on the continental shelf and at greater depths with half of the species found at about 2000 m or deeper. Viviparity seems to be correlated with a wide range of habitats. Oviparity, on the other hand, is unsuccessful in shallow water but is more specifically adaptable to life in the depths.

Gross observations of the ovaries of specimens of viviparous (*Oligopus* and *Cataetyx*) and oviparous (*Dicrolene*, *Benthocometes*, *Dicromita*, *Neobythites*, *Bassozetus*, and others) brotulids suggest that among the viviparous forms there is a tendency for many eggs to ripen simultaneously. In the oviparous forms egg development appears to be a more continuous process; thus it is possible to find eggs in various stages of development. In the relatively constant abyssal environment where seasonal changes in light and temperature are not available to initiate seasonal gametogenesis, a continuing maturation process might occur. It would be of special advantage to organisms which form in low density populations. For oviparous brotulids it may well be true that any time is breeding time, in order to take reproductive advantage of relatively rare encounters in the murky depths.

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[*] Oviparous genera : *Acanthonus*, *Alcockia*, *Barathrites*, *Barathrodemus*, *Bassobythites*, *Bassigigas*, *Bassozetus*, *Benthocometes*, *Dicrolene*, *Enchelybrotula*, *Eretmichthys*, *Glyptophidium*, *Homostolus*, *Hoplobrotula*, *Itatius*, *Lamprogrammus*, *Leucicorus*, *Luciobrotula*, *Mastigopterus*, *Mixonus*, *Monomeropus*, *Monomitopus*, *Neobythites*, *Parabassogigas*, *Penopus*, *Petrotyx*, *Porogadus*, *Pycnocraspedum*, *Selachophidium*, *Sirembo*, *Tauredophidium*, *Typhlonus*, *Xyelacyba*. *Glyptophidium* and *Lamprogrammus* have reduced swimbladders and weak ossification, suggesting that these genera may be bathypelagic.

Viviparous benthonic genera : *Belottia*, *Bidenichthys*, *Brosmophycis*, *Brosmophyciops*, *Bythites*, *Cataetyx*, *Dermatopsis*, *Dinamatichthys*, *Diplacanthapoma*, *Dipulus*, *Grammonoides*, *Hepthocara*, *Lucifuga*, *Microbrotula*, *Monothrix*, *Myxocephalus*, *Oculospinus*, *Ogilbia*, *Oligopus*, *Pseudonus*, *Saccogaster*, *Stygicola*, *Stygnobrotula*, *Typhliasina*, *Xenobythites*.

Viviparous bathypelagic genera : *Parabrotula* and *Thalassobathia*.

[†] Bougis and Ruivo (1954) have studied the ovaries of several specimens of *Benthocometes robustus* and on the basis of indirect evidence suggest that Norman's oviparous group is actually viviparous. We must disagree with them but alas, only on the basis of negative evidence. Males of the viviparous group bear prominent intromittent organs. There is no such obvious external sexual dimorphism in the oviparous group. We have examined the ovaries of over a hundred specimens of the oviparous group, including *Benthocometes*, and have never encountered fertilized eggs, although they are commonly found in the ovaries of viviparous forms. Furthermore, we know of not a single literature report of fertilized eggs or young being found in females of the oviparous group.

Brotulids are not known to be photogenic, so that species and sex recognition also may be a considerable problem. It is known, however, that many oviparous species (and perhaps some viviparous as well) have prominent drumming muscles and expanded anterior ribs associated with the swimbladder. Certainly sound production must play an important role in the lives of these fishes. HARRY (1951), ROSE (1961), and others have described sexual dimorphism in the swimbladder of Ophidiidae, or the cusk eels, which are closely related to oviparous Brotulidae.

There is virtually no information on the young stages of any benthic, oceanic brotulid. Young are rarely taken in the plankton. *Cherublemma* (TROTTER, 1926) and *Spectrunculus* (JORDAN and THOMPSON, 1914) are probably pelagic juveniles. ROULE and ANGEL (1930) identified an unknown larval, pelagic ophidioid as *Pteridium atrum*. Larger juveniles of other species, *Bassozetus zenkevitchi* (RASS, 1955), *Neobythites phyllosoma* (PARR, 1933), and *Dicromita metriostoma* (ROULE and ANGEL, 1930) have been taken in midwater. These latter three are oviparous species; however, it is impossible to know whether midwater capture of young specimens indicates a pelagic phase prior to settling or whether individuals occasionally sally forth into midwater.

The deep-sea viviparous genus *Cataetyx* apparently has pelagic young. The genus is represented off southern California by the species *C. rubrirostris*, adults of which are known from depths between 375 and 668 m. Recent investigations with midwater nets in the Santa Catalina basin off southern California have shown that adolescents of this species are not at all rare in the plankton, with specimens being taken in an open net fished between 800 m and the surface over depths of about 1200–1300 m (we are indebted to Dr. ALFRED W. EBELING and Mr. ROBERT J. LAVENBERG for this information).

AHLSTROM (1959) has listed larvae of the viviparous species *Brosmophycis marginata* as occurring at about nineteen meters off southern California, a closing-net record.

TURNER (1936) noted the presence of ribbon-like absorbtive trophotaenia in ovarian embryos of the bathypelagic viviparous *Parabrotula*. COHEN (in press) has found similar structures in ovarian embryos of a shallow water benthic *Oligopus*.

We thus find in the large group of diverse dioecious demersal fishes belonging to the family Brotulidae evidence of mate location by acoustical means; oviparity and viviparity, the former common at abyssal depths, where the latter is virtually absent; the tendency toward simultaneous development of ovarian eggs in several degrees of maturity among the oviparous species which may indicate a prolonged spawning period; and the scarcity but not absence of pelagic juveniles which does not, however, preclude demersal development as the customary habit.

Family *Aphyonidae*

The ophidioid family Aphyonidae comprises four or five genera containing about a dozen species. The adults are fragile creatures with flabby skin and musculature, reduced ossification, and poorly developed eyes and lateralis system. MARSHALL (1960) has suggested that the entire assemblage is bathypelagic. Most of the species are known to be viviparous. NYBELIN (1957) has figured the intromittent organs of several and called attention to the large size of the eggs. We are at a loss to understand how the fishes find each other in midwater. Their eyes probably lack the ability to form images; there is no trace of a lateral line on the body; absence of a swimbladder precludes sound production, at least by that means, and the nasal capsules are not enlarged.

Order **Heteromi**

The habits of few major groups of vertebrates are as little known as those of the Heteromi. The annual reproductive cycle of *Notacanthus bonapartei* Risso has been followed by LOZANO CABO (1952), but data on neither fecundity nor larval development were reported. Further data has been generously provided by Dr. SAMUEL B. MCDOWELL, who is currently engaged in the study of the Halosauridae. He notes (personal communication) that one species, *Halosaurus güntheri*, appears to segregate by sex, for single trawlings included males or females but never both; and that olfactory structure can be sexually dimorphic. In males of *Aldrovandia phalacra* the posterior nostril is enlarged; in the males of all other species the tube of the anterior nostril is elongate; and in all male halosaurids the lamellae of the nasal organ are enlarged and lobulated. Similar modification are found in the males of *Notacanthus*. These olfactory modifications would suggest mate location assisted by olfaction.

Seasonal differences in spawning are suggested by catch data associated with *Aldrovandia affinis** (= *palida*) and *A. gracilis*, species commonly taken in the same trawl haul. But ovarian eggs approaching maturity are found in one or the other species, never in the two simultaneously.

An important clue may lie in the phylogenetic relationship of the group—one which has been shifted repeatedly within the hierarchy and which has recently been reviewed by MARSHALL (1963). Similarities in osteology of the head and trunk, eye 'spectacles,' scales, fins, etc., and the detailed structure of the swimbladder and associated organs suggest common ancestry with the true eels, Apodes. Heteromous fishes thus may have a leptocephalus larva.

The Heteromi, deep-sea dioecious fishes with sexual dimorphism in olfactory ability and perhaps adult distribution, thus *may* migrate to spawn in midwater as do some of their presumed apodal relatives and *may*, as young, be represented among the hordes of unidentified leptocephalus larvae which grace the shelves of our natural history museums.

Order **Xenoberyces**

Of the three families of this wholly deep water group, the Melamphaidae are meso- and bathypelagic, the Stephanoberycidae and Gibberichthyidae probably

*650–1150 fm (1189–2103 m) in the Gulf of Mexico and adjacent Atlantic.

benthonic. At least three species of melamphaids, *Melamphaes acanthomus*, *M. suborbitalis* (EBELING, 1962) and *Scopeloberyx nigrescens* (GREY, 1956 : 191) are known from depths beyond 2000 m. The young of these species of *Melamphaes*, however, are caught in water as shallow as 150 m and the young of most species are found in waters far shoaler than that of the adults, indicating either vertical spawning migrations or the ascent of buoyant eggs subsequent to fertilization. In *Melamphaes*, *Scopelogadus* (EBELING and WEED, 1963), and presumably the other genera, the sexes are separate and the species oviparous, and there appears to be no obvious sensory specialization for mate location. EBELING (1962 : 139,142) has discussed the reproductive status of expatriate adults—individuals living beyond the limits of reproductive tolerance—and (personal communication) is investigating gonadal structure found in such individuals. That atypical gonads should be expected is shown by a preparation made from a 110 mm *Scopelogadus beani**, a tissue scarcely recognizable as gonadal but probably a regressed or degenerate ovary.

No reproductive data of any kind are available for the xenoberycine family Gibberichthyidae, a monotypic family of which only the 31·5 mm-type of *Gibberichthys pumilus* (PARR, 1933 : 5–7; 21°44′N, 72°43′24″W; 7000 ft of wire) and a second specimen 91 mm long (PARR, 1934 : 36) have been reported. Data on the reproduction of the stephanoberycids, all of which attain depths as great as 2000 m, likewise have never been reported and the larvae remain unknown. Dissection of Gulf of Mexico and Caribbean specimens has shown that the gonads of *Stephanoberyx monae*, and those of *Scopelogadus*, and the berycoids *Anoplogaster cornuta* and *Gephyroberyx darwini* are atypically placed, being relatively short and thick, situated along the posterior edge of the abdominal cavity, and connected to the genital opening (which is distinct from the urinary pore) by a short duct rather than forming elongate bodies along the dorsal wall of the visceral cavity. The single *Stephanoberyx* sectioned, an 87·7 mm Gulf of Mexico fish†, was a male, the tissue in active spermatogenesis and containing mature tailed sperm. No sensory differences associated with sex were apparent.

We can thus conclude only that the Xenoberyces are, as far as is known, normally dioecious and without specialized structures for mate location; that the young of the pelagic family Melamphaidae develop in waters shoaler than the adult environment; and that the reproductive structure and function, and larval history, of the few benthonic forms is virtually unknown.

Order **Berycomorphi**

Among the berycoids, only the Anoplogasteridae (Caulolepidae) can be called deep-sea in our sense, the others being pelagic or more characteristically neritic, sublittoral, and coral reef forms. *Anoplogaster cornuta*, the juvenile of *Caulolepis longidens* as shown by BERTELSEN and GREY (*in* GREY, 1955 : 293), occurs as an adult from 900–4900 m while the young have been taken within 50 fm (91 m) of the surface (MAUL, 1954; GREY, 1955 : 296). The species is dioecious and without apparent sensory sexual differentiation thus similar to its inshore relatives in sexuality and larval habitat.

*R/V *Anton Bruun*, shakedown cruise, January 9, 1963, 39°10′N, 71°52′W, 1500 m.
†R/V *Oregon*; September 24, 1957; 29°07′N, 87°54′W; 600 fm (1097 m).

Order **Scleroparei**
Families *Cottidae and Cottunculidae*

Two species of sculpins are deep abyssal, *Zesticelus profundorum* from the North Pacific and *Cottunculoides spinosus* from off South Africa. Although cottids are common in shallow water, little is known of their reproduction. Eggs are apparently demersal (BIGELOW and SCHROEDER, 1953). Males of some species have prominent urogenital papillae (JENSEN and VØLSE, 1949; BOLIN, 1944), suggesting internal fertilization. Fertilized ovarian eggs have been observed in shallow water species (BOLIN, 1941). A specimen of the deep abyssal species *Zesticelus profundorum* in the U.S. National Museum was observed to have about twenty large eggs in its ovary. Another, 38 mm long, in the Stanford University collections, contained 44 large eggs about 2·3 mm dia. and a similar number of small ones, *ca.* 0·7 mm across. Thus these examples indicate low fecundity and suggest viviparity or parental care.

Family *Liparidae*

GREY (1956) lists thirteen species of deep abyssal liparids, and several more have since been recorded from depths below 6000 m (BRUUN, 1956; ANDRIASHEV, 1955a; RASS, 1958; NIELSEN, 1964). JOHNSEN (1921) suggested that some abyssal species could have been captured in midwater, and that two, *Paraliparis bathybius* and *Rhodichthys regina*, deep abyssal species from the Norwegian Sea, are bathypelagic but form aggregations and perhaps descend to the bottom to spawn. Most deep water liparids, however, are caught in bottom gear; one from a bottom trawl at 7230 m contained material in its stomach indicating a benthic existence (ANDRIASHEV, 1955a). Sex is apparently easily determined from examination of the gonads (*e.g.*, BURKE, 1930) and there is no indication that any species are other than dioecious. The eggs are apparently large and few, as one might expect of arctic and deep-sea forms (MARSHALL, 1953). JORDAN and EVERMANN (1898 : 2135) report ovarian eggs the size of a pea in *Careproctus gelatinosus*, and NIELSEN (1964) found eggs of up to 8 mm in diameter in his specimens of a new hadal form taken by *Galathea*. He also found eggs maturing in two distinct size classes. Neither pelagic eggs nor larvae of deep water liparids are known, and the large size and low number of ovarian eggs suggests benthonic development. That oral brooding may occur is suggested by the following observation of GILBERT (1895) on *Careproctus ovigerum* :

> " The type is a male with well developed testes, and contained in its mouth when captured a spherical mass of eggs evidently belonging to this species. The eggs measured 4½ mm in diameter and are well along in their development, the embryos distinctly visible through the very tough egg membranes. The general form of head and body can be made out, and the long, continuous dorsal and anal fins running backward to the tail. It is probably that the male fish protects the eggs in this manner until after hatching."

Sex specific structures of possible significance to mate location are not yet known in deep water species. SHMIDT (1950) has noted the occurrence of anal papillae in several species taken at 500–600 m in the Sea of Okhotsk, but the function is unknown.

Thus the Liparidae, probably predominantly benthonic dioecious fishes most of which probably fertilize their eggs externally, lay few but large eggs which probably develop demersally into large and well developed young. Oral brooding has once been suggested, and the details of mate location are as yet unknown.

Order **Percomorphi**

Family *Zoarcidae*

The family Zoarcidae contains about 150 species. They are mostly confined to polar and temperate regions of both hemispheres but are also found at great depths throughout the world oceans. GREY (1956) lists sixteen species (of which two, *Melanostigma* species, are probably bathypelagic) from 2000 m or below. To her list should be added six species described by ANDRIASHEV (1955, 1958). The best known species in the family is the eastern North Atlantic *Zoarces viviparus*, a shallow water form which, as its name implies, gives birth to living young. A related western Atlantic form, *Macrozoarces americanus*, is also a shallow water species but is oviparous. Virtually nothing is known of the biology of deeper species. In a statement as appropriate today as when it was written, JENSEN (1904 : 8) summarized the then existing knowledge of the reproduction of the zoarcid subfamily Lycodinae, to which belong all deep water eelpouts, as follows :

> " The Lycodinae are oviparous, the eggs are of considerable size and consequently relatively few in number. Collett has found ovarian eggs in *Lycodes esmarkii* which were 6 mm diameter and he puts their number at about 1200. In a specimen of *Lycodes frigidus* 500 mm long, I have counted 500 eggs each ca. 7 mm diameter. The eggs are large also in the smaller species; in *Lycodes vahlii* (from Iceland) I have found them to be 4·5 mm diameter, in *L. eudipleurostictus* 5 mm diameter (the number ca. 250) and in *L. agnostus* 4·5 diameter.
>
> The eggs are laid without doubt on the bottom, as no pelagic egg is known which could be ascribed to the *Lycodinae*. Thc brood also must apparently live on the bottom; tolerably small young, for example, have often been taken in the trawl which is dragged on the bottom, never, however, in the pelagic net."

The low fecundity of zoarcids suggests that some form of parental care may take place, and indeed this has been noted for shallow water *Macrozoarces americanus* (BIGELOW and SCHROEDER, 1953). No information is available for deep water forms. Classical studies by SCHMIDT (1917 and subsequent papers) on variation in *Zoarces vivparus* indicate the presence of many localized populations, and this, combined with the weak powers of larvae dispersal implied by JENSEN (1904) suggests the existence of aggregations of individuals. This has not been borne out by captures of the adults of deep abyssal species, which are most often taken singly. However, as ANDRIASHEV (1955) has pointed out, trawls which capture deep sea zoarcids catch undescribed species as often as previously known forms, which suggests that the deep sea fishing gear presently used is not very good at catching eelpouts. JENSEN (1904) and others have also called attention to the marked sexual dimorphism in the relative size and proportions of the head.

Thus all available data on the reproductive biology of the deep water zoarcids are circumstantial : the group contains both viviparous and oviparous species; eggs of deep water forms are very large and relatively few, are probably demersal, and produce young which probably develop in the bottom habitat and area of the parents. Sexual dimorphism is present, and some form of parental care should be expected.

Order **Pediculati**

Two of the three suborders of the Pediculati (or Lophiiformes) are represented in the deep sea : the Antennarioidea, with a number of deep living genera and species, and the Ceratioidea, all of which are bathypelagic.

Suborder **Antennarioidea**

The single genus of the antennarioid family Chaunacidae has been found in deep waters of all oceans but never in depths exceeding 2000 m. Young specimens are often caught bathypelagically but the adults seem to live close to the bottom. The ovary of *Chaunax* is of the same folded structure as is found in the antennariids, which produce large rafts of floating eggs (KRUMHOLZ, 1963; and for *Chaunax*, JAMES C. TYLER, personal communication), again suggesting epipelagic egg development although neither eggs nor rafts have been reported.

The Ogcocephalidae are known from both deep and shallow waters. A number of records show that representatives of the genera *Malthopsis*, *Halieutopsis*, and *Dibranchus* may reach abyssal depths, but it seems doubtful that any of the species have their centers of abundance there. All are benthic. Larval and postlarval specimens have been caught epipelagically by the *Dana* (unpublished) but in very small numbers compared, for example, with ceratioid larvae. These unidentified specimens may represent shallow water species and do not eliminate the possibility that the deep living species may undergo benthic or bathypelagic development.

Suborder **Ceratioidea**

Vertical distribution of adults : all the members of the ten families of the suborder Ceratioidea are deep-sea fishes. All are pelagic and most have been caught in nets fished far above the bottom. The numbers caught by bottom gear never exceed those expected as incidental pelagic catches. Adolescent and adult specimens of all the approximately 100 known species of deep-sea angler fishes have been caught at depths between 1000 and 3000 m, and all of those species known in sufficient numbers to permit an estimate occur most frequently within this depth range.

Detailed analyses of the vertical distribution of the abundant collections made by the *Dana* expeditions (BERTELSEN, 1951) do not indicate that those species rare in the collection are more common in the less intensively fished depths below 3000 m, or that the mature stages, which are unknown in most species, should be sought for in these greater depths.

The small collection of ceratioids from the *Galathea* confirms these views with a single possible exception. A bottom trawl fished at 3570 m caught a 43-cm specimen of a species closely related to *Thaumatichthys pagidostomus*. The fish, which the leader of the expedition, the late Dr. ANTON BRUUN, called *Galatheathauma axeli*, might have been caught pelagically at a shallower depth, but Dr. BRUUN believed that the species is benthic, mainly because of the ventrally-directed light organ which emerges from the underside of the membrane connecting the premaxillaries.

Mate location : the extreme sexual dimorphism of the ceratioids and the presence in some families of dwarfed males which become permanently attached to and parasitic on the females is well known and is generally accepted as an adaptation to the living conditions in the deep sea. The females have developed into solitary, floating, baited traps while the mate location is left solely to the males. The males, in contrast to the females, are able swimmers, lack light organs, have large eyes, and in most families, enormous olfactory organs.

BERTELSEN (1951 : 251) has discussed balance between recruitment and mortality rate as follows :

> " By exceeding their competitors in size and by the effectiveness of their specialised fishing apparatus the Ceratioid females which have escaped alive through their growth, are able to produce a large quantity of eggs at each spawning and probably reach a high age. This is accomplished at the expense of the number of mature females, their power to seek and the chance to meet the other sex in the dark. This handicap is counterbalanced by the sexual dimorphism of the Ceratioids. The males are comparatively good swimmers, and their specialised sense organs render them well suited to find and recognize the females, which in return are provided with specifically characteristic light organs and probably with specific smell. The fixing apparatus of the males makes it further possible for them to remain in contact with the female until spawning time or permanently. The rapid development of the fixing apparatus and of the testicles in the males brings with it also that males ready to become attached are more numerous than the females ready to receive them, thus increasing the chance of the female becoming fertilised. The specialisation of the males has taken place at the expense of their catching powers, size, and amount of semen. Their small size exposes them more to being devoured, but the attachment to the female shelters them from attack. The attachment probably leads to an economic use of the small amount of available semen, and in several families the reduced or lost power of fishing is replaced by the fact that the male grows to the female and obtains as a parasite its nutriment from the blood of the latter—thus being reduced to an organ whose single function is to produce semen, which in practice makes the female appear as a kind of self-fertilising hermaphrodite."

With respect to the nature of the attachment between male and female, however, PARR (1930, 1932a, and personal communication, 1964) has proposed an alternative explanation : that the enlarged liver is the most important factor in sustaining the life and growth of the male rather than nutrition received from the blood of the female.

Egg size and fertility : most known female ceratioids with attached males have large ovaries in varying stages of maturity. A *Ceratias holboelli* of 65 cm standard length with attached ripe male (BERTELSEN, 1943) was found to have nearly five million eggs in the ovary (4,740,000; the 95% confidence limits being $3{\cdot}0–6{\cdot}5 \times 10^6$). The eggs, which were immature, varied in size from 0·2 to 0·4 mm (av. 0·30 mm). For comparison with this representative of the largest ceratioid species, the eggs were counted in an adult *Edriolychnus schmidti* of 63 mm, which carried a parasitic male. In this specimen the ovary contained 9,100 ripening eggs which measured from 0·25 to 0·36 mm (av. 0·32 mm).

With the exception of large (40–58 cm) *Himantolophus* and a single 114-mm *Dolopichthys*, all examined females of those families in which the males are free-living are immature. In contrast to the aforementioned specimens; the *Dolopichthys longicornis* contained eggs of two distinct size groups : about 10,800 ripening eggs of 0·5–0·75 mm (av. 0·65 mm), and nearly the same number of eggs (about 10,300) in early stages measuring 0·1–0·3 mm (av. 0·23 mm).

Ovoviviparity or viviparity seems unlikely in ceratioids and no information indicating internal fertilization is recorded.

Larval development : the ceratioids pass their larval life in epipelagic waters. Larvae of most species are rare in depths greater than 200 m and are most abundant in water shallower than fifty. Larvae of the family Linophrynidae live somewhat deeper, being most abundant between 100 and 200 m. The young ceratioids sink to depths between 1000 and 3000 m during metamorphosis. Females tend to descend further than the males, which are most abundant at about 2000 m and continue their development there. After metamorphosis, most females rise to layers between 1000 and 2000 m and descend again when older.

Spawning season : analysis of the catches of ceratioid larvae from the *Dana* expeditions, which have fished at all times of the year in the North Atlantic, shows that here at least the common ceratioid species have an annual and more or less sharply defined spawning season. The majority are summer spawners, the maximum number of larvae occurring in July of August. The linophrynids spawn during the spring, their larvae being taken almost exclusively during March, April, and June.

Data on the suborder Ceratioidea can be summarized as follows : all species are pelagic, solitary living and show extreme sexual dimorphism. The dwarfed adult males are more numerous than the mature females and are adapted for mate location by having very large eyes and olfactory organs, while the females have species-specific light organs. Males attach themselves to the females, either temporarily or as permanent parasites, increasing the chance of fertilization. Ceratioids are dioecious, oviparous, and produce a large number of small eggs. Spawning is seasonal and the larvae are epipelagic, entering deep water at metamorphosis after a larval life of several months' duration.

DISCUSSION

Certain environmental changes are known to occur with increasing depth—changes not well understood in detail. The lack of sunlight and consequent loss of primary autotrophic organic production must lead to the restriction of food supply, at least in midwater, and a consequent reduction in the total weight of fishes which can be supported by this food supply (see, for example, ZENKEVICH and BIRSTEIN, 1956; MARSHALL, 1960 : 109). That the benthic food supply is more concentrated than the bathypelagic is certain, but comparative values of productivity and standing crop are difficult to obtain and existing estimates uncertain (*e.g.* THORSON *et al.* in ZOBELL, 1954 : 23–26.) This reduction in supportable biomass of fishes can be accomplished by increasing or decreasing size of individual *and* size of population (or by holding one factor constant while decreasing the other) in a way so correlated to achieve the required reduction in biomass. Deep sea fish populations are known to be sparse compared to those in upper layers and the bathypelagic fishes are in general small. Another possible adaptation to the restricted deep water food supply would be a reduction in the energy requirements of the fishes. To what extent such reduction has occurred is unknown, for no determination of their metabolic rates has been possible and little is known about age, growth, and mortality. However, most bathypelagic fishes are thought to be less active than surface forms and in general have poorly ossified skeletons, soft and degenerate musculature, and reduced organ systems.

The abyssal *benthic* fauna shows clearly that the required adaptation has been accomplished at the expense of population size* and not through a notable reduction in the size of the individual fish or of level of organization.

Low population density and low activity will reduce the probability of chance meetings between mature individuals. This, combined with the darkness and the unchanging environment in time and space, could be expected to produce specializations to facilitate communication leading to the fertilization of gametes. We have reviewed the evidence and will return to the question after discussing the second principal problem : How has the balance between fecundity and the survival of eggs and young, a balance essential to ensure adequate recruitment to the adult population, been achieved ?

The survival of fish fry, or of any other organism, depends on the availability of suitable food and on predation pressure in a broad sense. Both we assume to decrease with increasing depth in the ocean, rising again on and near the bottom but never to the levels found in the epipelagic zone. A small and poorly organized larval fish must be surrounded by a high concentration of small food items which can be obtained by sight or merely by random feeding movements, but a larger and more highly organized young fish will be able to collect more scattered and larger food items and may to a greater degree be able to hunt by means other than the sense of sight.

The environmental advantages of large eggs and correspondingly advanced hatchlings in the deep sea, as in polar waters, have been discussed by MARSHALL (1953), RASS (1941), and others. With a given amount of energy which can be used for reproductive purposes, an increase in the size of eggs and thus of hatchlings can be achieved at the expense of egg number. Hence one would expect deep-sea fishes to tend toward one of the two available alternatives : the production of many small eggs with development in productive surface waters, or the production of few but large eggs which hatch into advanced young which develop in the deep sea. This indeed seems to be the case.

In certain groups we find the retention, with modification, of the typical spawning habits of oceanic fishes from higher levels of the sea : high fecundity and epipelagic development. This is the pattern found in all of the bathypelagics studied, in the benthic eel *Synaphobranchus*, and perhaps in a few others. For example, the ceratioid fishes and the eels, the most numerous of the abyssopelagic fishes, have numerous, relatively small eggs and larvae which develop epipelagically, the young surrounded by abundant food but subject to high mortality through predation. Among such fishes, parental care in the absence of a substrate seems unlikely and viviparity is unknown.

Others have assumed the polar, and to a certain extent the deep-sea invertebrate pattern (THORSON, 1950; MARSHALL, 1953; BARNARD, 1962 : 11) : low fecundity, with large young and a tendency toward some form of parental assistance with the reduction or suppression of the pelagic phase. This we find suggested by the benthic forms exclusive of the eels and perhaps a few others. For example, the benthic representatives of the Macrouridae, the deeper-living Brotulidae, Liparidae, Zoarcidae, and some Clupeoidea have large yolky eggs. Viviparity occurs in only two abyssal brotulids and perhaps in some Scleroparei as well. However, in most other abyssal benthic species the young are well supplied with yolk and we suspect (although mainly on the basis of negative evidence) that they develop either bathy- and abyssopelagically and are subject to predation pressure lower than that near the surface, or demersally, perhaps with parental care. Types intermediate in habit may exist; some alepocephalids may be among them.

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*Drs. Bruun and Bernard, in the accompanying discussion of the benthic fish density data of JOHNSTON (1962 : 219), observed that data from bathyscaphe observations and deep-sea photographs indicate densities greater than those estimated from trawl hauls. This is to be expected. Donald W. Bourne, of the Museum of Comparative Zoology, Harvard University, and the Woods Hole Oceanographic Institution, has examined several series of deep-sea photographs assembled by Dr. J. B. Hersey and his group in Woods Hole. Bourne's data, still preliminary and subject to many qualifications, also suggest populations more dense than trawl catches would indicate.

How do abyssal fishes insure fertilization of gametes ? Most species are dioecious, thus raising the problem of mate location. In the two most speciose and abundant groups of abyssal benthic fishes, the Macrouridae and Brotulidae, sound production and reception probably play an important role in sexual attraction, or at least in maintaining contact among individuals and perhaps thereby aiding in the formation of aggregations.

Another important mechanism is bioluminescence. The ceratioids, some elasmobranchs, stomiatoids, searsiids and some alepocephalids, and most pelagic Iniomi display luminescence which is often sexually dimorphic. The increase in olfactory structure may be associated with sexual communication in certain groups such as the Heteromi, and this is certainly true among the ceratioids.

The monoecious Iniomi are unique among abyssal fishes. If they are truly functional hermaphrodites they have achieved the ultimate in insuring fertilization, at the cost, however, of genetic variability. Regular self-fertilization seems unlikely. Also unique are all the ceratioids in which the males and females are mechanically united, temporarily or for life.

We should mention the condition observed in certain alepocephalids, liparids, and many others in which more than a single group of eggs develops simultaneously, and the related condition in Brotulidae, with numerous sizes of eggs in a single ovary. These may be ways of extending the breeding period and enabling reproductive use of relatively rare encounters in low density situations. The demonstration of superfoetation among these fishes would not be unexpected.

How does reproduction in the deeps compare with that in other waters ? Known or suspected among deep abyssal fishes are examples of direct and indirect development and parental care, sexual dimorphism in form and sensory structure, demersal and pelagic eggs, oviparity, ovoviviparity and viviparity, simultaneous hermaphoroditism, shoaling, and spawning migration. None of these is unique to the deep sea, and coastal and fresh water fishes also include in their reproductive repertory parthenogenesis and gynogenesis, hermaphroditism with self fertilization as well as protandry and proterogeny, and superfoetation—these would be difficult to demonstrate from deep abyssal material if present. The parasitic attachment of the dwarf ceratioid males to their females, and the widespread hermaphroditism in the deep water Iniomi appear to be unique to the abyssal fish fauna.

We are well aware of the exceptions to our generalizations and of the weakness of our argument. Our parting statement is well-worn but appropriate—more work remains to be done, work which should include the further search for eggs and young near the bottom and in deep midwater localities, the continued study of gonads, eggs and the reproductive cycle, investigations of age, growth and longevity, and the search for the sensory modalities and associated structures of significance in sexual communication or identification.

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Galapagos Rise in the southeastern Pacific*

H. W. MENARD†, T. E. CHASE‡, S. M. SMITH†

(*Received* 26 *November* 1963)

Abstract—An oceanic rise, the Galapagos Rise, exists in the southeast Pacific between the East Pacific Rise and South America. It is faulted into segments by transverse fracture zones and is seismically active in some portions. The Galapagos Rise appears to extend from Panama to Chile and the previously known Chile Rise may form the southern part.

REGIONAL BATHYMETRY

A NEW bathymetric map of the southeastern Pacific and the sounding lines on which it is based are given in Fig. 1. The soundings were originally plotted on U.S. Oceanographic Office 3000-series plotting sheets at a scale of about one to one million. Lineations were established, where Scripps echograms permitted, by comparing detailed profiles and the echograms themselves. This technique permits far more accurate contouring than is possible with even closely-spaced soundings. Chief criteria used to establish lineations are the occurrence of a sequence of asymmetrical ridges and narrow deep troughs on more than one echogram in a small region. Echograms and profiles are also used to plot regions of ridges and troughs on more widely spaced sounding lines, and the occurrence and trend of these regions are sometimes helpful guides to the location of contours. Contours prepared on the one to one million scale were then reduced optically to a scale of about one to six million. The change in scale revealed certain probable lineations which were then re-examined on the original plotting sheets and recontoured if they appeared real.

The principal features disclosed by the study are a section of an oceanic rise centered at about 95°W long. and 15°S lat.; a second small section of an oceanic rise centered at about 28°S, 95°W; a very linear fracture zone trending almost east–west at 26°S; some minor and problematical lineations on the east flank of the East Pacific Rise; and several belts of ridge and trough topography of which the most prominent is on the east flank of the East Pacific Rise (Figs. 1 and 3).

The chief feature which should be eliminated from published charts is a long elevation based on one old sounding line on a course from California to Valparaiso, Chile. Four recent Precision Depth Recorder sounding lines between 10° and 20°S cross the older line and show that it is consistently 500 m too shallow. A second feature which requires major modifications is the so-called San Felix–Juan Fernandez Ridge which is based largely on shallow soundings in which the bottom was not reached.

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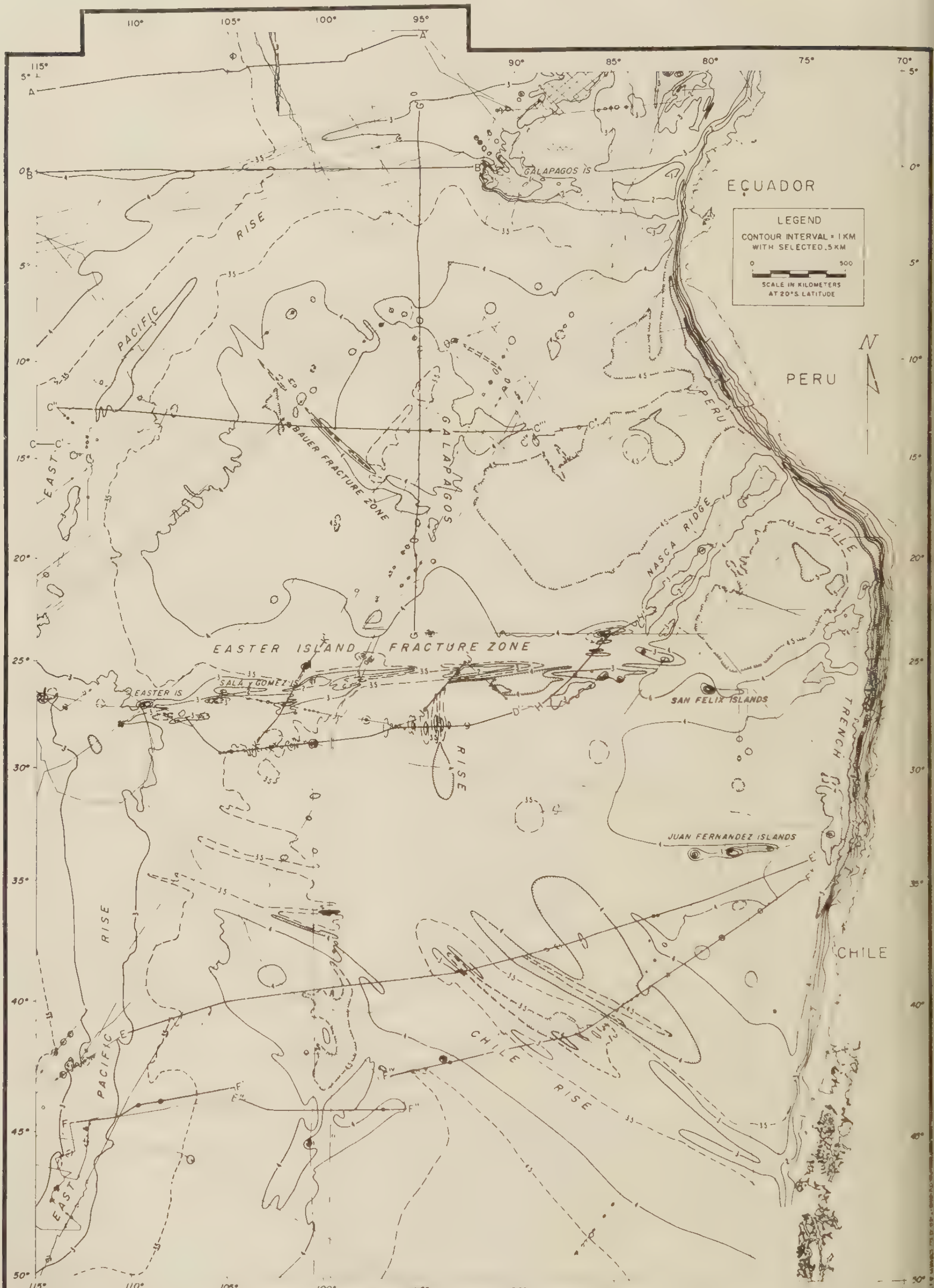


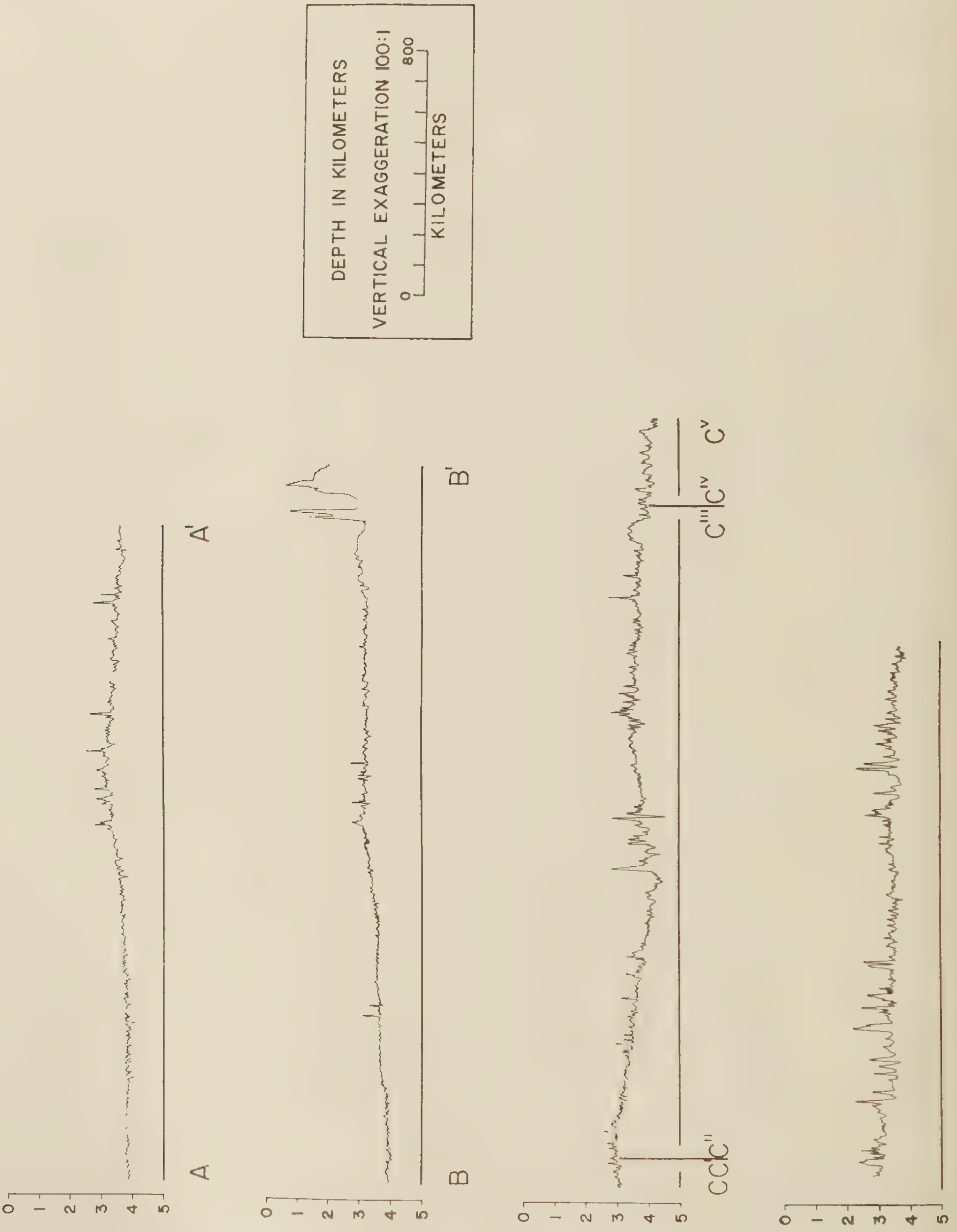
Fig. 1. Bathymetric chart of the southeastern Pacific. Tracks shown as light lines. Profiles as heavy lines.

GALAPAGOS RISE

A vast submarine elevation, originally called the Albatross Plateau (Murray and Renard, 1898), was discovered in the southeastern Pacific by the *Challenger* Expedition and surveyed by several expeditions of Alexander Agassiz on the *Albatross* (Agassiz, 1906). Thus the broad outlines of the regional bathymetry were known prior to 1910. Few other soundings were made until 1946 when the U.S. Navy began the studies of the Antarctic which still continue. Logistic support required sending ships through the southeastern Pacific and soundings accumulated very rapidly. Charts published since 1950 include these Navy soundings (e.g. the General Bathymetric Chart of the Oceans published by the International Hydrographic Bureau, Monaco). Scripps Institution of Oceanography sent the first of five expeditions into the region in 1951. The three most recent expeditions, *Downwind*, *Step I*, and *Risepac*, have obtained very long sounding lines in previously little known regions. The new soundings indicate that previous interpretations of the bathymetry of the southeastern Pacific have been biased by a few erroneous sounding lines, and that a virtually unsuspected oceanic rise lies between the East Pacific Rise and South America.

The newly discovered elevation in the southeastern Pacific is here named the Galapagos Rise after the nearest important subaerial feature. In the southeastern Pacific Basin, the rise is about 1400 km wide and asymmetrical with a crest west of center. A region about 200 km wide along the crest is characterized by ridges and troughs, and one trough is about 400 m below the surrounding region. The rise is clearly defined for only a distance of 900 km along its axis between boundaries which appear to be minor fracture zones (Figs. 1 and 2, profiles C and G) with trends roughly perpendicular to the crest of the rise. The southern fracture zone, here named the Bauer fracture zone after the Bauer Deep which lies on it, can be traced for about 2000 km. The only echogram across it shows two asymmetrical ridges separated by a trough which extends about 1000 m below the regional depths (profile C). The trough can be identified on a number of closely-spaced spot sounding lines in the region. At the intersection of the fracture zone and crest of the Galapagos Rise is the Bauer Deep of 5320 m discovered by *Carnegie* (Revelle, 1944). The deep is about 1500 m below the surrounding region and resembles the extraordinary deeps, such as the Romanche Deep, found on the Mid-Atlantic Ridge where the crest is intercepted by fracture zones. The fracture zone is not seismically active where it is best sounded, but, if extended a few hundred kilometers to the northwest, its intersection with the crest of the East Pacific Rise is marked by a minor regional change in depth and a cluster of epicenters (Fig. 3). The intersections of fracture zones with active rises are characteristically active seismically (Menard, 1960) and thus it appears that the Bauer fracture zone extends to the crest of the East Pacific Rise.

Between the Bauer fracture zone and the great Easter Island fracture zone the sea floor is deeper than to the north or south and the crest of the Galapagos Rise has not been identified. South of the Easter Island fracture zone, the rise can be identified between 27°S and 29°S on *Downwind* echograms (Fig. 2, profile D). The crest has a belt of asymmetrical ridges and troughs but the troughs do not extend below the regional depth. The western edge of the rise lies at 98°W and the eastern edge seen on *Downwind* echograms is at 90°W, indicating a width of only 800 km. However, the *Downwind* track trends northeasterly into the fracture zone on the east side of the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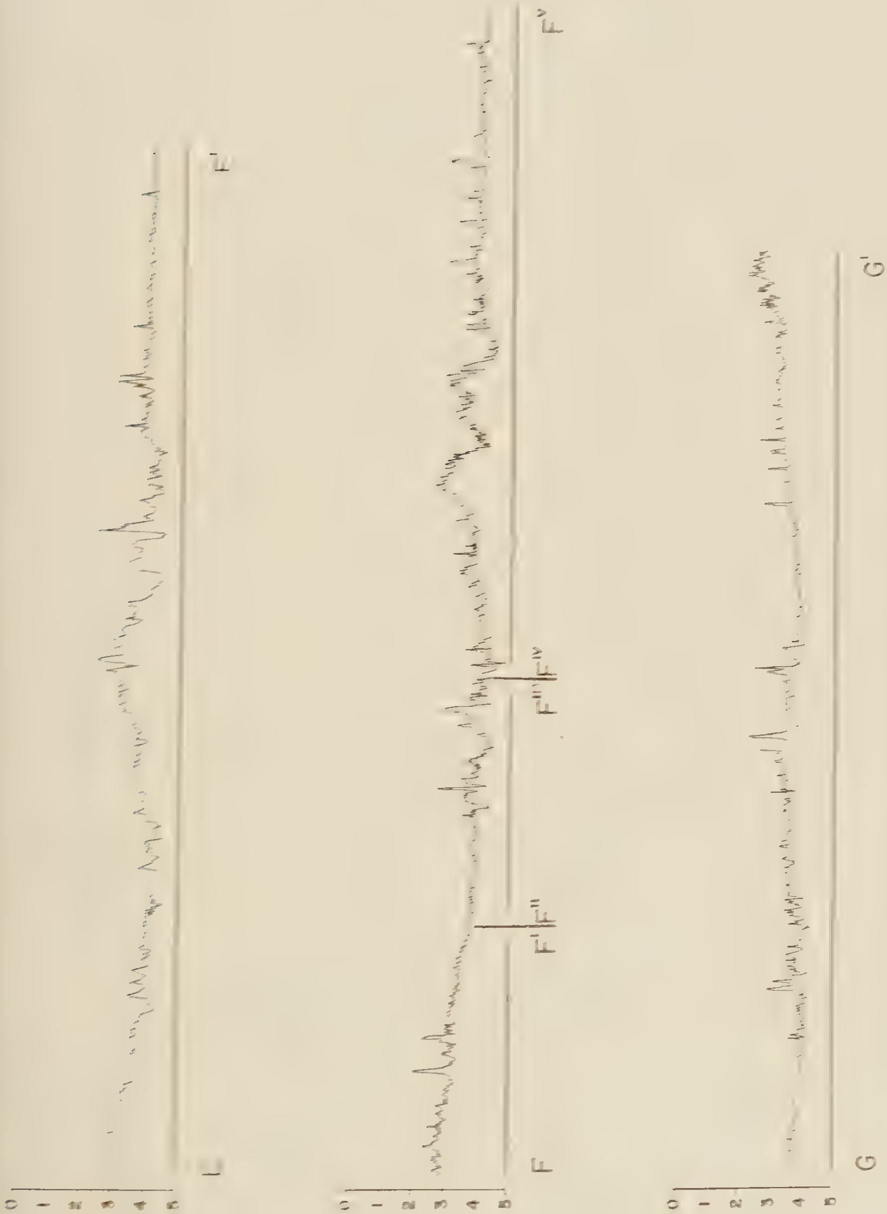

Fig. 2. Profiles of the Galapagos Rise. Locations given on Fig. 1.

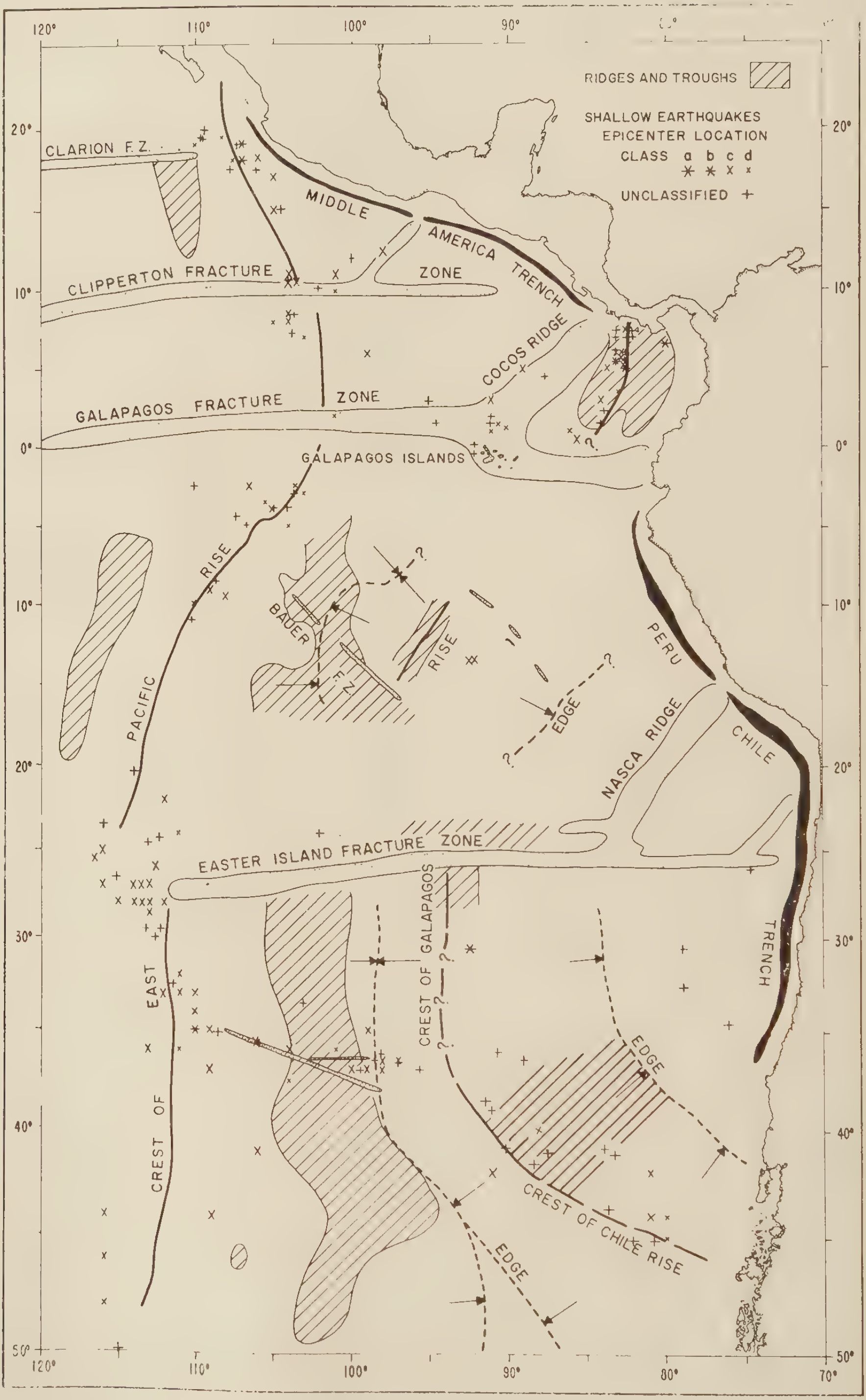

Fig. 3. Structural diagram of the southeastern Pacific. Epicenter locations from GUTENBERG and RICHTER (1954) and SYKES (1963). Numerous earthquakes near the continental margins are not shown.

rise and it is unlikely that the eastern edge of the rise was crossed. Spot soundings suggest that the rise extends to 85°W, giving a width of 1400 km. If so, the Galapagos Rise in this region is very similar to the region to the north, namely asymmetrical with the crest west of center, and with a belt of ridge and trough topography on the crest.

A sounding line between Easter Island and Valparaiso was taken during the I.G.Y. Depths along the track are indicated on a recent chart of the Pacific Basin by Udintsev. A basin deeper than 4000 m lies along the line of the crest of the rise and may mark a widening and deepening of one of the troughs found to the north on *Downwind.*

South of the *Ob* track is a region of 700,000 km^2 which contains only four soundings by *Carnegie*. This unknown region introduces a 550-km gap in the contours of the rise. To the south are several sounding lines which show an asymmetrical rise about 1400 km wide and with a belt of ridges and troughs on the crest which is west of the center. This rise can be traced southeast into Chile. Judging by dimensions and topography, it appears that the Galapagos Rise may be the same feature as the Chile Rise. The latter feature was discovered by EWING and HEEZEN (1956) who predicted the existence of an elongate submarine elevation on the basis of earthquake distribution and the correlation between the crest of mid-ocean ridges and a known seismic belt. The prediction was confirmed during the *Downwind* expedition with regard to the eastern section of the seismic belt. EWING and HEEZEN (1956, Fig. 1) connected the Chile Rise to the East Pacific Rise because of a group of epicenters which jut east from the East Pacific Rise in this region (GUTENBERG and RICHTER, 1954; SYKES, 1963). This group is separated from the epicenters associated with the known topography of the Chile Rise by a gap of 400 km which may not be significant. On the other hand, the Galapagos Rise is also seismically active and the gap between epicenters on it and on the Chile Rise is 600 km. On the basis of epicenter distribution, the northwesterly extension of the Chile Rise is uncertain. Considering general trend, the Chile Rise may bend either north or west but does not continue on a straight line. Physiography is also ambiguous with regard to the extension. The belt of ridges and troughs on the crest of the Chile Rise is not unlike the ridges and troughs on the adjacent east flank of the East Pacific Rise (profiles E and F). However the belt of ridges and troughs on the east flank of the East Pacific Rise appears to be elongate parallel to the crest (Fig. 3) which implies that it is not related to the Chile Rise.

From existing data it is not clear whether the Chile Rise bends sharply north and connects with the Galapagos Rise to form a single Galapagos-Chile Rise, or bends west and joins the East Pacific Rise. If the Chile Rise joins the Galapagos Rise the group of epicenters on the flank of the East Pacific Rise at 36 S to 37 S requires some explanation. The topography in the region consists of a line of troughs and ridges separating regions with different depth. This type of topography occurs either along the crests of oceanic rises and ridges or roughly perpendicular to the crests on fracture zones. Thus the epicenter belt may lie along a transverse fracture on the east flank of the East Pacific Rise as suggested by SYKES (1963).

EASTER ISLAND FRACTURE ZONE

The Sala y Gomez Ridge was tentatively identified by FISHER and NORRIS (1960) as part of a fracture zone similar to those in the northeastern Pacific. The contours presented here, substantially different from those in their Figure 1, indicate a continuous zone, named here the Easter Island fracture zone after the well known island. The difference of contours results in part from additional soundings from *Step I* expedition and from Navy sources, and in part from a different philosophy of contouring.

The maximum topographic expression of the fracture zone occurs between Easter Island and the intersection of the zone with Nasca Ridge, a distance of 2700 km. The effect of the zone may be seen beyond these points, however, by the offset of the crest of the East Pacific Rise and by the presence of a broad swell of less than 4000 m depth which continues east of the Nasca Ridge intersection. The regional depth changes across the zone, the sea floor to the north being several hundred meters deeper than that to the south.

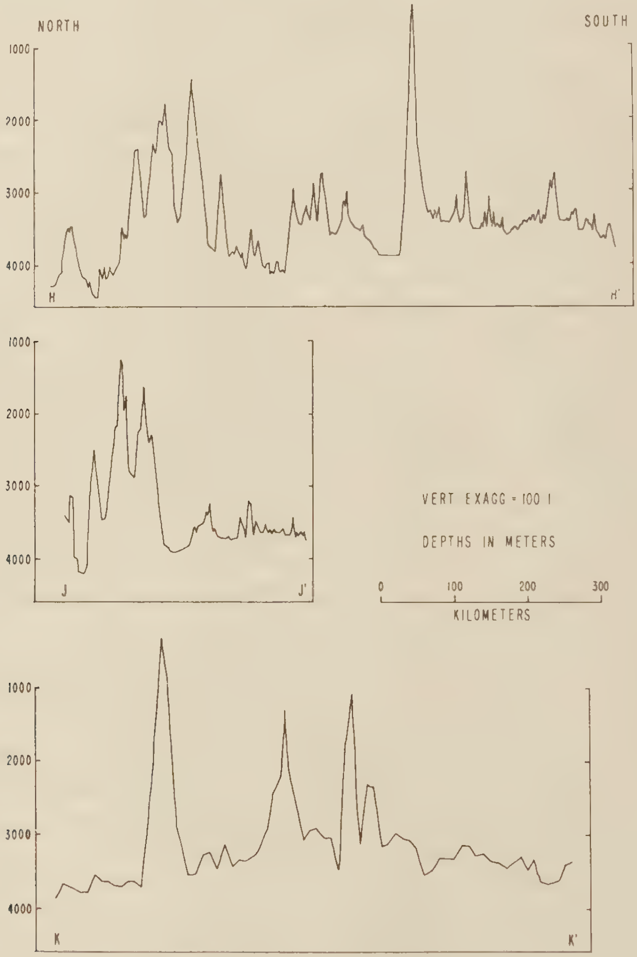

Fig. 4. Profiles of the Easter Island fracture zone.

All three profiles in Fig. 4 have a prominent ridge on the south edge of the zone with a trough at the base on the north side. Profiles H and K which cross the entire zone each show two more elevations north of the main ridge. In each profile, the smaller one on the south is an asymmetrical ridge. The more symmetrical topographic high to the north may, in each case, be a ridge or an isolated seamount.

The northern limit of the Easter Island fracture zone is not well defined from the present sounding lines. West of the Nasca Ridge, *Downwind* expedition crossed only the southern ridge and the widely spaced soundings on the Navy lines are not sufficient to distinguish ridge type topography from individual seamounts. Several areas of rugged 400 m relief, 50 km wide, were encountered on the east–west track of *Step I* at 24°S between 90° and 95°W. Such topography would be observed if the ship passed along the northern edge of the zone. Future sounding lines may show that the features at 98° and 101°W, north of the main ridge, which are presently contoured as individual seamounts, are in fact ridges within the fracture zone. The zone would then have a width of 160 km, about average for the western parts of the eastern Pacific fracture zones.

DISCUSSION

A special investigation by one of us (Chase) indicates that the region south of Panama has all the characteristics of the crest of an oceanic rise. It has ridge and trough topography, high seismicity, and high heat flow. This is probably the northern extension of the Galapagos Rise. Including the connected or closely adjacent Chile Rise, the Galapagos Rise thus intersects western South America at its northern and southern boundaries. The effects of this intersection appear to be profound (Fig. 3). Almost all the features associated with the Peru–Chile Trench are confined to the region bounded by the intersections of the rise. The trench itself, deep focus earthquakes, and lines of active volcanoes are so confined, and the southern boundary of intermediate focus earthquakes also corresponds to the intersection of the rise with South America. A similar relationship applies to the northern limit of the Middle America Trench and the intersection of the East Pacific Rise with North America.

The Galapagos Rise is roughly parallel to the East Pacific Rise for several thousand kilometers. Both are seismically active but the latter is much more so. Moreover the Galapagos Rise is chopped into segments by transverse fractures whereas the crest of the East Pacific Rise in the southeastern Pacific appears to be much less faulted. This meager evidence suggests that the East Pacific Rise may be somewhat younger than the Galapagos Rise and it is possible that faulting on the flanks of the East Pacific Rise of the type demonstrated in the northeastern Pacific (MENARD, 1960) is responsible for cutting the Galapagos Rise into offset segments.

The implications of the existence of the Galapagos Rise may be quite important with regard to the origin and history of oceanic rises and ridges. Two rises separated crest to crest by only 1400–1600 km and roughly parallel for several thousand kilometers exist in the southeastern Pacific. One is obvious, but, because of sounding distribution, the other has only just been discovered even though it is as broad as the Mid-Atlantic Ridge in the North Atlantic. It may be anticipated that other obscure oceanic rises and fragments of rises exist and that the distribution of active rises has varied markedly in geological time. Moreover adjacent parallel rises imply complications in the origin of oceanic rises which have not previously required explanation.

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GUYOTS IN THE SOUTHWESTERN PACIFIC BASIN

Geological Society of America Bulletin, v. 75, p. 145–148, 2 figs., February 1964

hort Notes

. W. MENARD
. M. SMITH
. E. CHASE

UYOTS IN THE SOUTHWESTERN PACIFIC BASIN

bstract: Four guyots in a northwest trending roup of guyots, 2000 km east of New Zealand, ave reliefs of 4200–4500 m and shelf break depths f 700, 880, 900, and 920 m. Blocky and tabular obbles of olivine basalt and detrital rock were redged from one of the guyots. The structural province characterized by northwest trending lines of volcanoes has greater extent to the southwest than previously known and comes into contact with the sub-continental Tonga-Kermadec and Fiji structures.

A group of guyots in the Southwestern acific Basin is of unusual interest because it is ar from other existing and ancient islands and et shows the northwesterly trend and basaltic ithology typical of the whole Pacific Basin. he group was discovered by various ships of he U. S. Navy sailing to and from New Zealand in connection with the exploration of Antarctica. The group was first noted by the Hydrographic Office. One guyot was surveyed and dredged in 1961 during the Monsoon Expedition of the Scripps Institution of Oceanography of the University of California.

Four guyots have been discovered along a

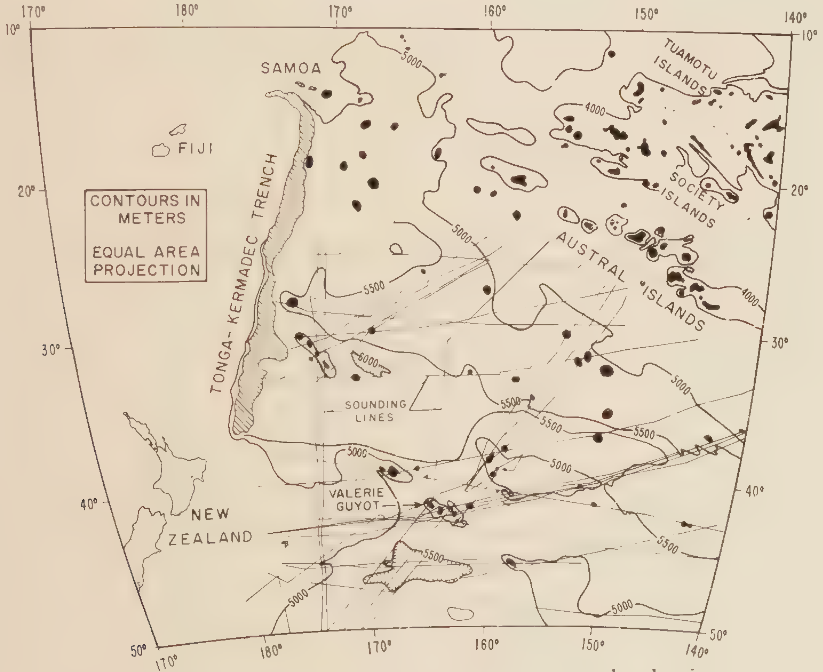

Figure 1. Known distribution of seamounts and volcanic islands in southwestern Pacific. Widely spaced spot soundings not shown. Pronounced northwesterly trend of ocean basin volcanoes is evident.

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line about 1100 km long (Fig. 1). They have remarkably accordant flat tops with shelf breaks at depths of about 700 m, 880 m, 900 m, and 920 m. Each is a rather isolated volcano with local relief of 4200–4500 m, which is greater than that of most drowned ancient islands in the Pacific.

Valerie Guyot, named after the wife of
of the expedition leaders, is 50 km wide
probably about 100 km long, although neit
end was surveyed (Fig. 2). It appears to
asymmetrical with steep eastern and south
sides. The smooth and almost flat top is 9 by
km, slopes gently from a depth of 776 m

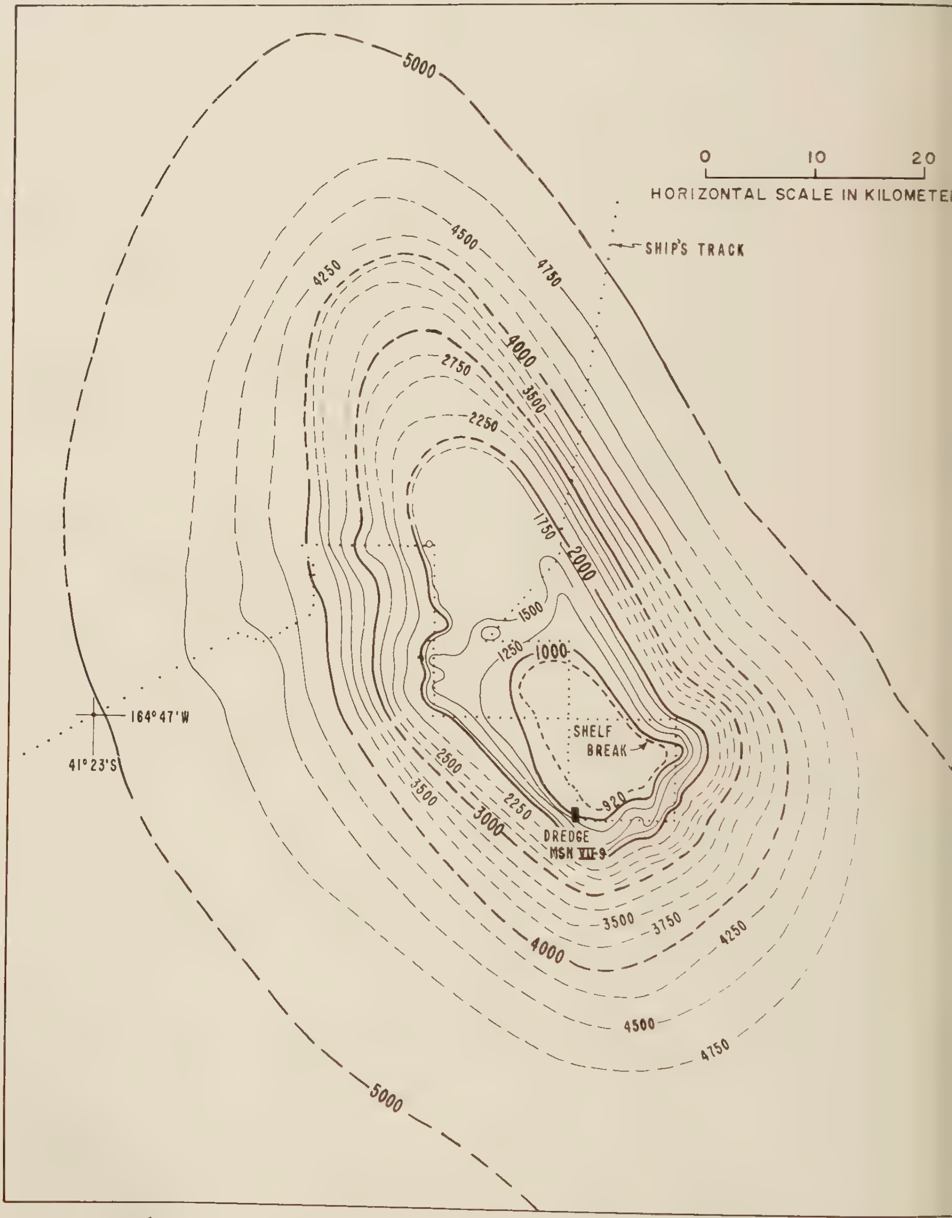

Figure 2. Bathymetry of Valerie Guyot, Southwestern Pacific Basin. Ship's track is that of Ar
on Monsoon Expedition. Original discovery soundings made during Operation Highjump cann
be located accurately relative to survey and are not shown. Contour interval = 250 m

e center, and is limited by shelf breaks at
pths of 863, 955, 977, 1004, 1096, and 1097
in different places. Differences in depth may
rely reflect uniform truncation of a slightly
egular cone. Relief of the smooth top from
nter to shelf break is about 220 m, which is
too great to have resulted from even the
st prolonged marine planation without a
ange in depth. This guyot, like many others
the Pacific, was once an island surrounded
a gently sloping shelf. Very slow subsidence
abled waves to cut into the island until
thing remained except a continuous shelf
ping out from what had been the center.

A single dredge haul (Monsoon VII–9) was
ade across the shelf break and brought up 100
of blocky and tabular cobbles of olivine
salt. The curved tabular pieces have a uni-
m aphanitic texture and are highly weath-
d, suggesting rapid chilling and long surface
posure. The blocky cobbles have less surface
athering, and some show rounding. Their tex-
re is porphyritic with phenocrysts of labradorite (1–5 mm) and olivine (1–2 mm). Labradorite microlites, olivine, opaque devitrifying glass, and small amounts of pyroxene make up the groundmass. Several 2-cm pieces of detrital rock composed of angular to subrounded grains of weathered basalt (1 mm) cemented by carbonate were also present.

This group of guyots is about 2200 km southwest of the nearest oceanic islands, the Austral group, but the two trends are very close to parallel. Thus the Pacific structural province characterized by northwesterly trending lines of large basaltic volcanoes is far more extensive than previously known. Another group of large submarine volcanoes, not known to be guyots, is centered at about 32°S., 173°W. (Fig. 1). The province butts into, or is interrupted by, the Tonga-Kermadec and Fiji structures. Previously, considering the distribution only of existing islands, it appeared that the province did not intersect this sub-continental salient into the Pacific Basin.

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p. 2

OBSERVATIONS ON ADVERSE RELATIONS BETWEEN THE HYDROID, *HYDRACTINIA ECHINATA*, AND CERTAIN MOLLUSKS.

Arthur S. Merrill, U. S. Bureau of Commercial Fisheries and Biological Laboratory, Oxford, Maryland.

(Abstract)

Hydractinia echinata **is a polymorphic hydroid that grows by increasing the number of individuals in a colony. The hydroid lives frequently as an epizoon on the external shell surface of the sea scallop,** ***Placopecten magellanicus.*** **When a colony reaches the shell edge of the scallop it expands over and around the shell margin and attempts to establish on the internal shell surface. This intrusion interferes with normal mantle activity of the host scallop, which in turn affects growth and causes shell malformation.**

Observations indicate that gastropods, too, are not immune to the effects of direct association with ***Hydractinia echinata.*** **Several species (*Nassarius trivittatus*, *Lunatia heros*, *Buccinum undatum*, and *Epitonium greenlandicum*) were observed to have reacted to the presence of the advancing zooids of a colony by enlarging the area of their apertures. The apertures often become badly deformed, extremely enlarged, and globose.**

Thus, ***Hydractinia echinata*****, which normally uses a shell simply as a substrate, is capable of becoming a harmful epizoon. This type of relationship in which one of the associates is inhibited while the other is not affected is best described by the term** ***amensal*** **as defined by Eugene Odum (1953,** ***Fundamentals of Ecology*****, W. B. Saunders Company, Philadelphia).**

Estimating the Natural Mortality Rate of the Sea Scallop *(Placopecten magellanicus)*

BY ARTHUR S. MERRILL[1][2] AND J. A. POSGAY[1]

Abstract

A method is described for estimating the natural mortality of sea scallops. The method is based on the percentage occurrence of the persistent paired valves of scallops that died from causes other than fishing collected along with live animals. Estimates of the average length of time that the paired valves remain attached at the hinge are calculated by determining the age in years and months when the animals died, and by measuring the time difference between modal groups in frequency distributions of live and dead animals. The possible causes of natural mortality are discussed. It is concluded that the average instantaneous natural mortality rate of the stocks in Subarea 5Z during the years 1959-1963 was about 0.10.

Introduction

Estimating the natural mortality rate for any wild population is a difficult task. In fishery investigations, it is frequently done by estimating total mortality rate from an analysis of the relative decline in numbers of several year classes as they pass through the fishery and then subtracting the fishing mortality rate which has been estimated by marking experiments.

This method is not feasible in the sea scallop fishery since only the shucked meats are landed, and it is not possible to collect data on the age composition at the time of landing. Since the animal is sedentary and the fishing grounds wide spread, it would be prohibitively expensive to collect a long series of samples for analysis of the age structure of the fished stock. Marking experiments are difficult to interpret for mortality rate estimates since the marked animals do not distribute themselves at random through the population, but remain where they are released (Posgay, 1963).

By fortunate circumstance, however, it is possible to identify a sea scallop which has recently died from causes other than fishing. When a fisherman shucks a scallop, he separates the two valves in order to get at the edible adductor muscle. Shells of sea scallops which die from other causes are left with the hinge intact. The soft parts decompose or are eaten by scavengers, but the paired valves, called "clappers" or "cluckers" by the fishermen, persist for some time.

This fact led Dickie (1955) to propose a direct method of estimating the natural mortality rate. He reasoned that, if the rate is constant, the number dying and adding to the clapper population should be equal to the number being removed by the hinge ligament decomposing. Knowledge of the average time required for the valves to separate would provide an estimate of deaths per unit time. In his calculations for the Bay of Fundy stocks he used the results of some unpublished tank experiments which gave an average time of 100 days required for separation of clappers larger than 96 mm. Relating the number of clappers to the number of live scallops in the population would give an estimate of the mortality rate.

Realizing the importance of Dickie's method for determining natural mortality, investigators at this Laboratory have kept records of clapper-live shell relationships on all sea scallop research cruises since 1958.

It is apparent that the accuracy of Dickie's clapper method for estimating natural mortality is dependent, among other things, on the accuracy of estimating the number of days the valves hold together. It was our desire to increase the reliability of his method by obtaining an estimate of the time required for separation on the fishing grounds. To do this we have actually aged live and clapper shells from samples to determine how long the clappers had been dead. Aging was accomplished by reading the annual rings on the

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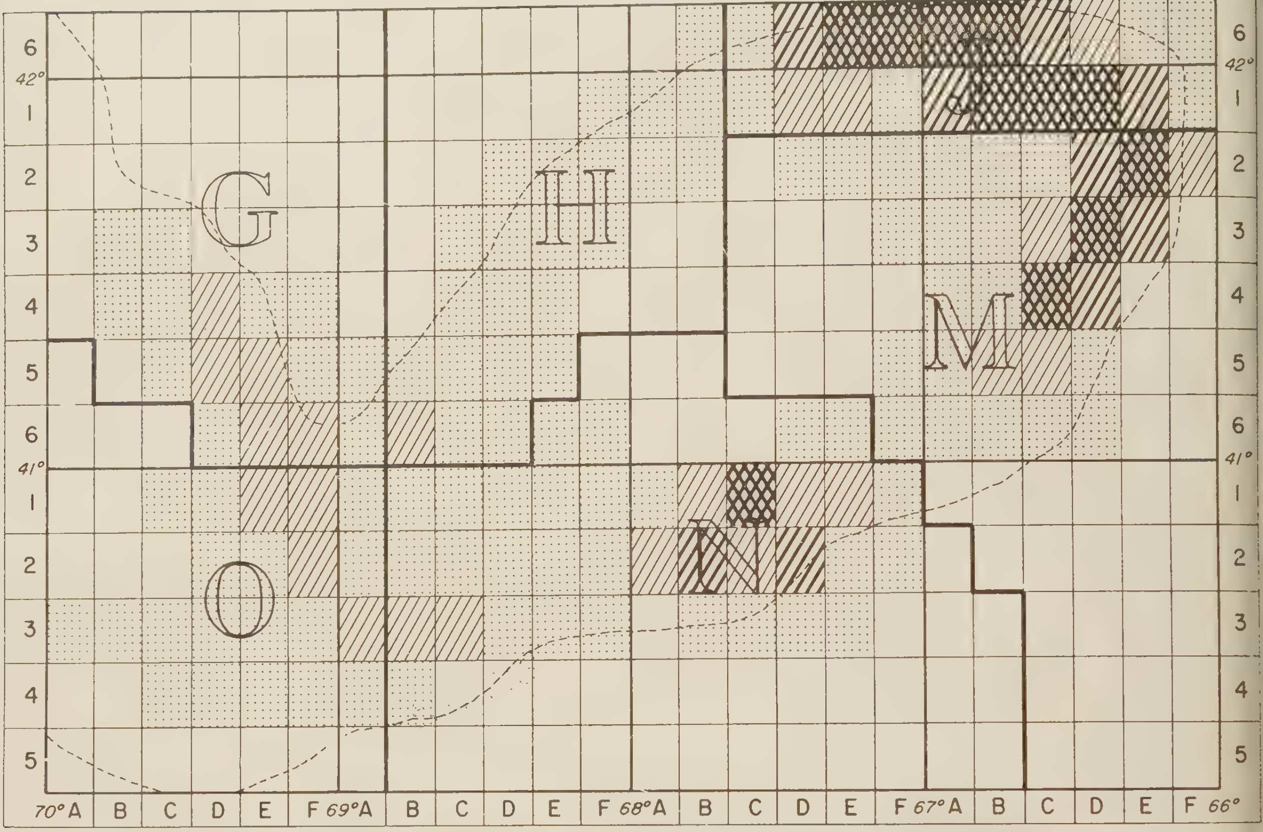

Fig. 1. The sea scallop grounds of Georges Bank showing the division into unit areas and Statistical Subareas. Th shading of the unit areas represents the relative productivity of the different areas. The lightly shaded area produced average annual landings of less than 100,000 pounds (45 metric tons) of meats during the year 1944-1961. The next darker areas supplied between 100,000 and 200,000 pounds (45-90 metric tons). Th areas with the next darker tone supplied between 200,000 and 300,000 pounds (90-135 metric tons). The 1 areas with the darkest tone supplied more than 300,000 pounds (135 metric tons) per year. In all, there wer about 250 million pounds (113,636 metric tons) of sea scallop meats, 39 percent from the most heavily shade areas, landed during the 18 years.

shell. We have full confidence in this method of aging, having recently validated the reading of annual marks on the shell of the sea scallop (Merrill, Posgay, and Nichy, in press).

This paper presents the clapper shell and live scallop data collected from all the Georges Bank (Fig. 1) fishing grounds during the years 1958-1963. From the available evidence, it appears that clappers hold together for varying periods of time depending upon the conditions of the environment. Ways and means of determining most accurately the probable average length of time clappers hold together in particular areas are discussed. It is concluded that, (1) natural mortality varies considerably on Georges Bank, and (2) natural mortality is low over most of the Bank.

Area of Investigation

Although the sea scallop is known and fishe from the Gulf of St. Lawrence to the offing of th Virginia Capes, it occurs in greatest abundanc on Georges Bank off the coast of Massachusetts In our investigation of the ecology of the sea scallop and the effects of the fishery on the stocks we have, therefore, concentrated our efforts o these grounds. They are in ICNAF Subarea 5Z

In reporting our data we have used the uni area, 10 minutes of latitude by 10 minutes o longitude, as our basic unit. These are named b the degree square in which they occur; the letter A to F from west to east, and the numbers through 6 from north to south. For example l /66 E-2 is located between 41°40′ and 41°50′ and 66° 10′ and 66° 20′ W. In these latitudes hey have an area of about 75 square miles (194 km). The next larger unit is the subarea as efined by the North American Council on Fishy Investigations (Rounsefell, 1948). These are ttered G, H, O, J, M, N. We have also comined subareas G. H, and O into what we will call rea Group 1, Subarea N into Area Group 2, and ubareas J and M into Area Group 3. Fig. 1 hows the Georges Bank fishing grounds with hese divisions outlined.

The three Area Groups are not equal in area. rea Group 1 has 60 unit areas fished for sea scalops: Area Group 2 has 36 unit areas fished; Area roup 3, 49 unit areas. In all, the exploited rounds on Georges Bank total 145 unit areas, pproximately 11,000 square miles (28,490 q km).

Collection of Data

We have made 11 cruises to Georges Bank uring the past 6 years concerned directly with ea scallop research. The cruises were designed or specific purposes; the recording of clapper-live hell length-frequencies often was incidental. On some cruises only a few areas were sampled while on others a large portion of the Bank was urveyed. In general, however, stations within he three major Area Groups were sampled every ear. In addition, a valuable set of clapper-live callop data from a 1961 research cruise to Georges Bank made by Canadian scientists was kindly iven us for incorporation into this report. In 960 and 1961 samples of clappers and live shells rom an area of high clapper ratio were brought back to the laboratory for analysis.

Distribution of Live and Clapper Shells on Georges Bank, 1958-1963

Table 1 lists the number of 10-minute tows aken and the number of live scallops and clapper hells found in the unit areas investigated during each cruise. The clapper ratios are the result of dividing the number of clapper shells taken by he number of live scallops. For *Delaware* cruise 60-8, and all subsequent United States cruises, here is an additional column headed "density ndex." These data were obtained by towing an odometer behind the dredge to measure the distance traveled over the bottom and then reducing ll catches to the common base of numbers of live scallops caught per 10,000 square feet (929 sq m) dredged.

Figs. 2-7 show the clapper ratios measured for each of the unit areas sampled during each year. If a unit area had been sampled during more than one cruise in the year, the clapper ratio was calculated by pooling the catches of all the samples collected during the year. A dot has been placed in each unit area which was sampled but yielded no scallops. A brief summary of each cruise is presented below.

1958

Albatross III Cruise 113

Albatross III cruise 113 (Table 1), June 1958, surveyed Georges Bank adequately. No clappers were found in Area Group 1, and no scallops were taken in Area Group 2. The clapper ratios were very low in Area Group 3.

Dartmouth Cruise 1

Dartmouth cruise 1 (Table 1), September 1958, worked mostly in Area Group 3. The clapper ratios were low, the highest .0351 in one unit area to the east.

1959

Whaling City Cruise 3

Whaling City cruise 3 (Table 1), May 1959, covered eight scattered unit areas. The first evidence of rather high clapper ratios was discovered on this cruise.

Whaling City Cruise 4

Whaling City cruise 4 (Table 1), September 1959, was restricted to concentrated sampling in four unit areas. However, at least one unit area was in each Area Group. As with the earlier cruise, the clapper ratios were low in Area Groups 1 and 2, higher in Area Group 3.

1960

Delaware Cruise 60-8

Only one cruise was made in 1960. *Delaware* cruise 60-8 (Table 1), May 1960, sampled rather adequately the three Area Groups. As usual, few clappers were found in Area Groups 1 and 2. Large numbers of clappers were found in Area Group 3; the highest ratio, .4406, in one unit area on the Northern Edge.

1961

Delaware Cruise 61-7

Delaware cruise 61-7 (Table 1), May 1961, surveyed Georges Bank quite thoroughly especially in known scallop producing areas. Again few clappers were found in Area Groups 1 and 2, while large numbers were taken in Area Group 3. One unit area on the Northeast Peak had a clapper ratio of .4585.

Delaware Cruise 61-13

The purpose of *Delaware* cruise 61-13 (Table 1), August 1961, was to do gear selection work. Most of this was done in a limited area in Area Group 3.

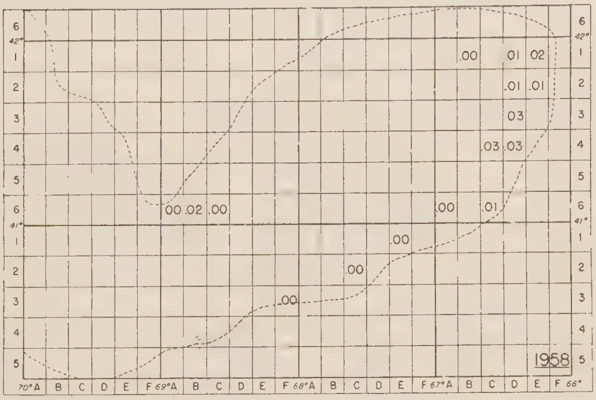
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Fig. 2. Clapper ratios observed in 1958.

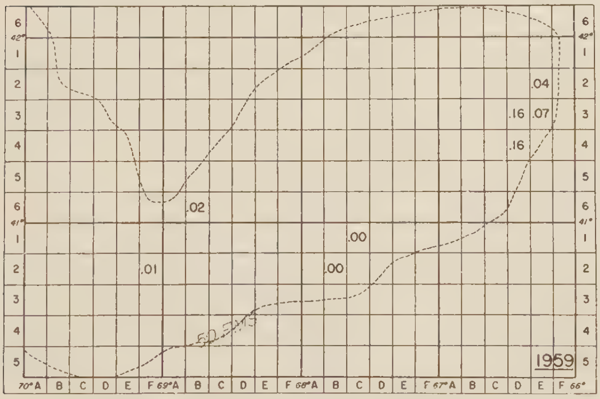
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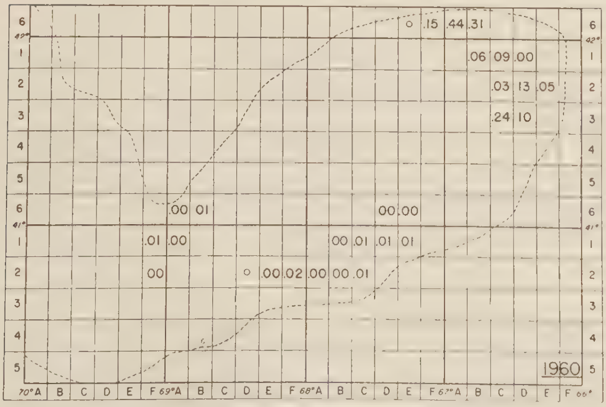
Fig. 3. Clapper ratios observed in 1959.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1960
70° A B C D E F 69° A B C D E F 68° A B C D E F 67° A B C D E F 66°

Fig. 4. Clapper ratios observed in 1960.

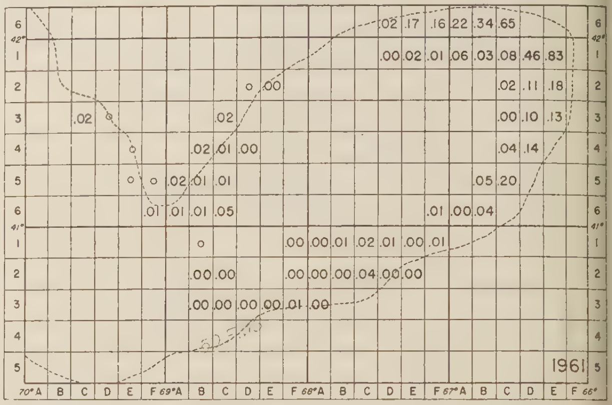


Fig. 5. Clapper ratios observed in 1961. Notice the high ratios in some of the northern and eastern unit areas. These are the same areas shown in Fig. 1 as being the most highly productive.

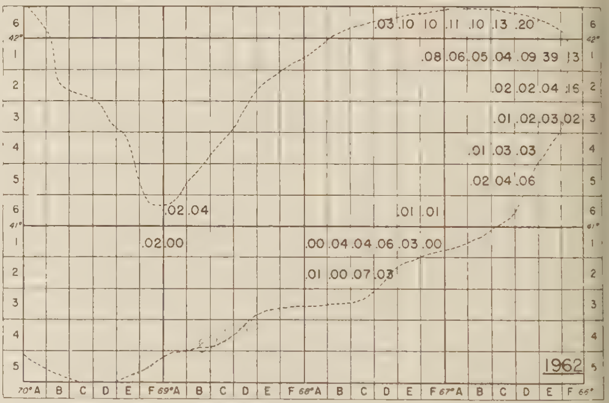


Fig. 6. Clapper ratios observed in 1962.

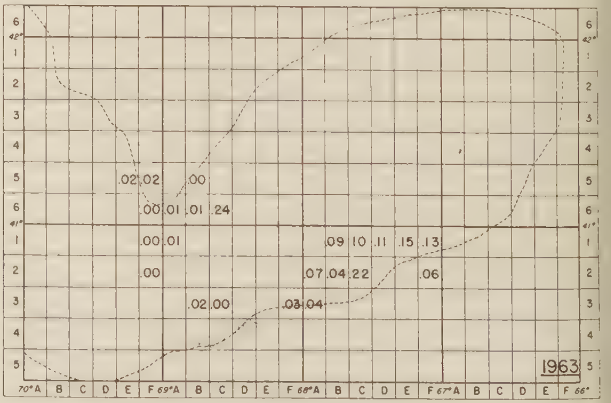


Fig. 7. Clapper ratios observed in 1963.

ape Eagle Cruise

Cape Eagle cruise (Table 1), September 1961, ncentrated efforts in three selected unit areas in ea Group 3. Each unit area was subdivided to many smaller units and systematically mpled. The clapper ratios resulting from this anadian cruise in which many samples were ken from a unit area compare favorably with apper ratios from United States cruises in 1961 here only a few samples were taken from the me unit area.

elaware Cruise 61-16

Delaware cruise 61-16 (Table 1), September 961, surveyed a large area of Georges Bank. he clapper ratios were similar to the May cruise ith few clappers in Area Groups 1 and 2. One nit area in Area Group 1 showed a high ratio of appers, but the ratio was based on only a few ve and clapper shells. Area Group 3 showed rge numbers of clappers. Two unit areas on e Northeast Peak had extremely high ratios, 300 and .6476.

elaware Cruise 62-6

Delaware cruise 62-6 (Table 1), May 1962, gain surveyed a large area of Georges Bank. he clapper ratios were low as usual in Area roup 1, but in Area Group 2 there were more appers than usual, the highest ratio was .0734 one unit area. Clapper ratios continue generly high in some unit areas in Area Group 3, though the data indicate that ratios were lower han in the preceding 2 years in many unit areas.

elaware Cruise 62-10

Delaware cruise 62-10 (Table 1), September 962, concentrated effort in Area Group 3. Sampng was extended to include a number of additonal unit areas, and more tows were made in ach one of them. Although clapper ratios are ill high in some unit areas, the number of unit reas with high ratios is fewer, and not generally s high as in the preceding 2 years.

lbatross IV Cruises 63-1 and 63-3

These two cruises were made in late May and arly June 1963. Cruise 63-1 was interrupted ecause of equipment breakdown, and the station lan completed on Cruise 63-3. Samples were ollected only in Area Groups 1 and 2. Clapper atios were moderately high in some locations; he highest was .2433.

Examination of the data of Table 1 produces wo interesting facts. In general, high clapper ratios did not occur before 1960. Pooling all the samples collected in 1958 gives a ratio of .0133; the 1959 samples a ratio of .0208, although two unit areas, 41-66 D3 and D4, had ratios greater than .15. The average clapper ratio in the samped areas rose to .1131 in 1960 and then dropped to .0723 in 1961; it was .0620 in 1962, and .0845 in 1963. The other point, seen most clearly in Fig. 5, is that all of the higher clapper ratios occur in those unit areas which are along the northeastern rim of the Bank.

Analysis of Shell Samples

The amount of time that has passed since any individual clapper was formed can be estimated by a study of the shell. A clapper can be aged by reading annual rings on the shell just as a live specimen can. By this means it is possible to estimate the month in which it died. Further information regarding time of death can be gathered by observing the clapper shells for kinds and degrees of fouling, and for the degree of erosion to shell and hinge ligament. Gunter, Dawson, and Demoran (1957) undertook experiments along these lines in Texas and Mississippi waters to determine time of oyster mortality. They described the initial fouling complex and dominants at different levels below the surface at various seasons of the year and concluded the rate of fouling to be strongly dependent upon temperature. Conditions differ somewhat in deeper, colder water where sea scallops are found, because bottom temperatures are more uniform and the season of setting of fouling organisms is shorter. Moreover, we are interested in fouling succession as well as initial setting in determining the period of time a clapper holds together. The two valves of a sea scallop gape at each side even when fully closed; as soon as it dies, the adductor muscle relaxes, and they gape fully. This enables minute organisms to enter and utilize the interior shell substrate of a clapper as soon as the animal matter has deteriorated or has been eaten by another organism. Thus, it is possible to study the fouling organisms that settle on the interior part of a clapper shell to help determine how many years have passed since the scallop died.

In August 1961 (*Delaware* cruise 61-13), a sample from unit area 42/66 B-6 in Area Group 3, which contained live and clapper scallops, including associated fouling organisms, was quick-frozen aboard ship and brought back to the laboratory for study. Two dredges were towed simultaneously on this station. The live scallops from both dredges totalled 1125, the clappers 516 (clapper ratio .4587). The length frequencies of these are shown in Fig. 8. The live scallops from one dredge (about half, 508) and all the clappers (516) were studied in the laboratory. About 60 percent of the live scallops were of the same year class (Fig. 8, mode at about 110 mm).

Before the scallops could be aged, the exterior of the shells had to be thoroughly scrubbed to remove foreign growths and expose the annual rings. The interiors of the clappers were left untouched as far as possible to study the degree and complexity of fouling. The cleaned shells revealed exceptionally clear rings, particularly those which had formed in 1959, 1960, and 1961 (Fig. 9).

The length that each of the live scallops had attained at the time that each annual ring had formed was measured. The average size at each ring is shown in Table 2 and Fig. 10. These results agree very well with other samples that we have analyzed from the same general area.

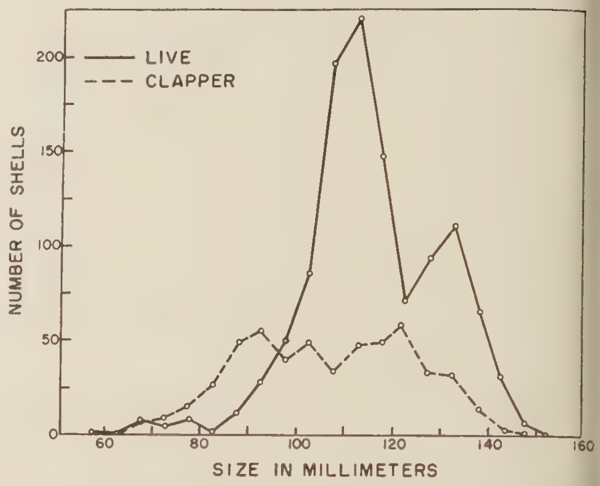


Fig. 8. Length frequency distribution of the live and clapper shells collected in August 1961 from unit area 42/66 B-6.

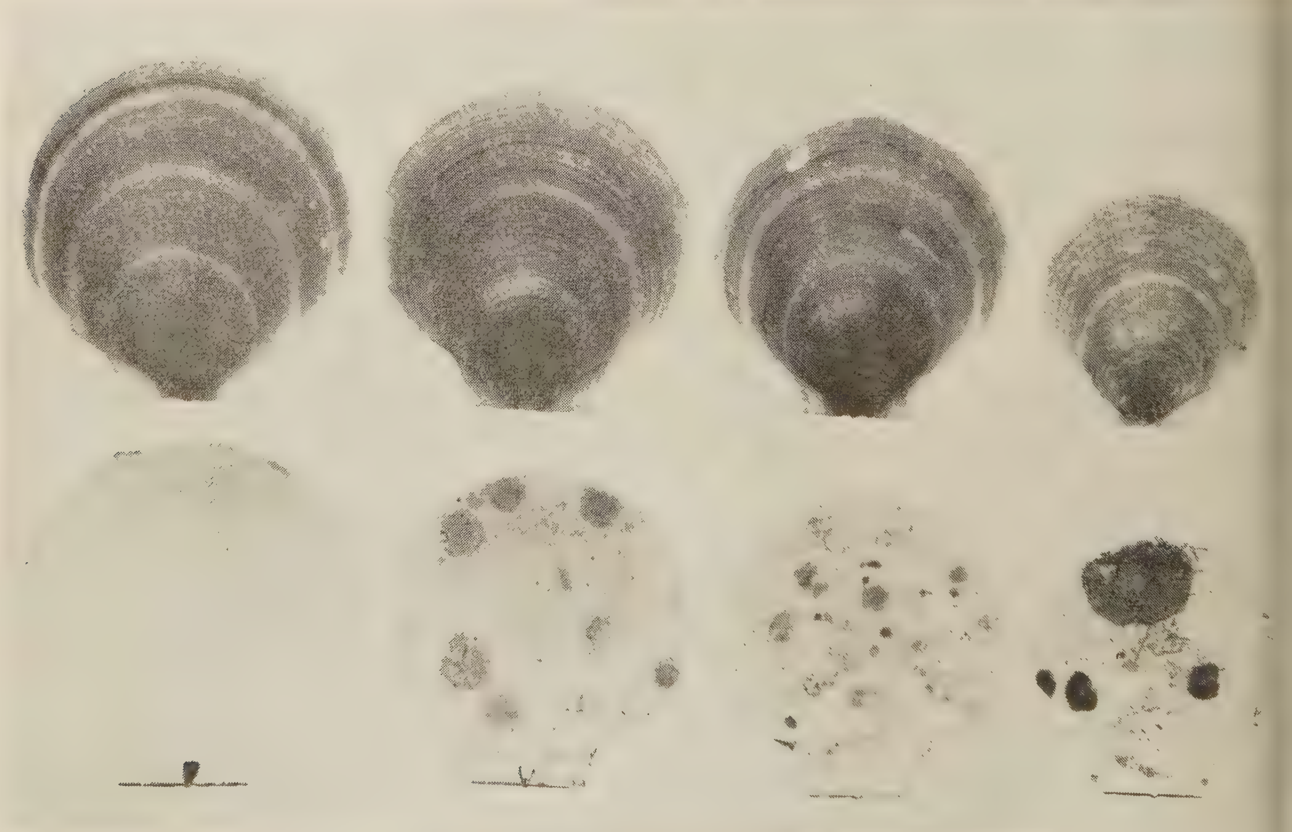
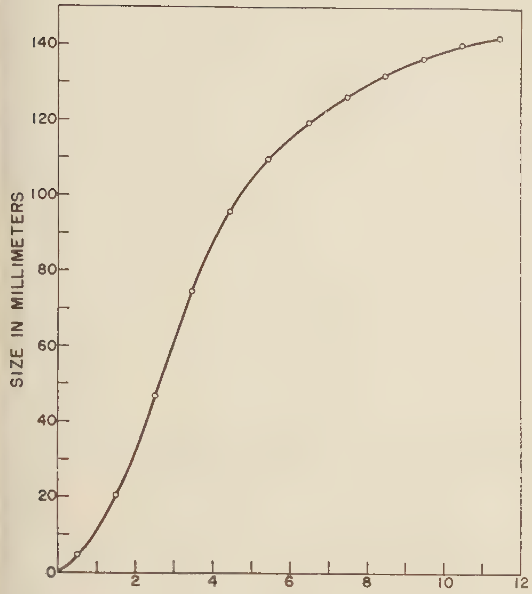


Fig. 9. Exterior (top row) and interior (bottom row) surfaces of the left valves of some clapper shells collected in August 1961 from unit area 42/66 B-6.



. 10. Growth curve of a sample of 508 live sea scallops collected in August 1961 from unit area 42/66 B-6.

The annual ring forms on the sea scallop in e spring time (Merrill, Posgay, and Nichy, in ess). For the purpose of this paper we have bitrarily chosen March 1st (6 months before e sample was taken) as the exact date the ring ished forming each year. We well understand, wever, that it may vary from year to year and en from shell to shell in the same year. By ing this we have a constant with which to mpare rates of growth between rings for any rt of the year. At the same time the fouling owth on the shells was studied to determine the ensity of fouling, the kinds of organisms in- lved, and their probable time of setting.

The clappers were first separated into their spective ring groups. The amount of shell ded since the formation of the last ring was en used to estimate the amount of time that d elapsed between ring formation and death. scallop with three rings, for example, that had own 7.5 mm after the third ring had formed, s assigned July as its month of death since the erage rate of growth between the third and rth ring was 1.76 mm per month. The fol- wing criteria were then used to assign a specific ar of death to each clapper. A clapper had d within 6 months if:

1. The last three rings were extremely clear.
2. Little to moderate fouling growths were on the interior of the valve.
3. The hinge ligament showed little deterioration.
4. The interior of the shell was glossy.

A clapper had been dead between 6 months to 18 months if:

1. Only the last two rings were extremely clear.
2. Fouling growths were extensive with new encrusting growths overgrowing old ones.
3. The hinge ligament was completely deteriorated.
4. The interior of the shell had lost its high gloss.

A clapper had been dead 18 months to 30 months if:

1. Only one ring was extremely clear.
2. Fouling growths were not only extremely extensive but succession in fouling was evident.
3. The valve showed evidence of actual decay.
4. The interior of the shell was stained and discolored.

The clappers, after being aged and having a time of death assigned to them, were arranged by year class in the order of the month and year that they had died (Table 3). Here can be seen clappers that had remained together for as long as 2 years. This was the time when we first noticed large clapper ratios. The mean period of time clapper valves in this sample had remained together was 36 weeks. These data also show that clappers from the three youngest year classes had been dead less than 18 months. This may be due to the fact that small clapper scallops separate sooner than the larger ones. Dickie (1955) states that scallops under 96 mm hold together on the average only half as long as those larger. Examination of the clapper frequency distributions also show few clappers under 80 mm which also suggests either that small clappers separate quickly or perhaps fewer die.

Some of the clappers were so heavily overgrown with fouling organisms that the valves could not have separated even had total deterioration of the hinge ligament allowed them to. This points out the difficulty of estimating an average length of time that clappers hold together from tank experiments. Conditions of the natural environment must be taken into consideration.

If epizooty or predation had caused mass mortality most of the scallops would have died about the same time. The data in Table 2 show this not to be the case. Fig. 11 shows a plot of the data of Table 3 grouped by quarter years. The total numbers show a progressive rise in the number of clappers formed each quarter from the time the sample was taken back to the fourth quarter. Further back in time the numbers are lower each quarter.

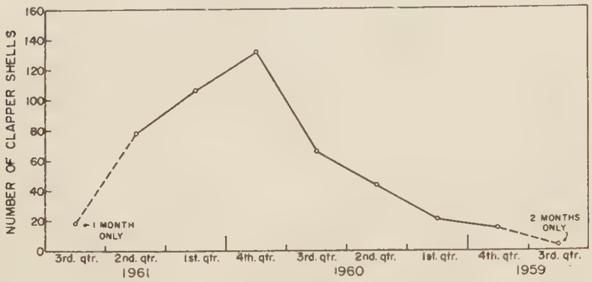


Fig. 11. Dates of death for the clapper shells collected in August 1961 from unit area 42/66 B-6. The modal group had died about 36 weeks before collection.

Using the size of the clapper shell when it was collected, the estimated time that it had been dead, and the average growth rate (Fig. 10), we were able to estimate the size that each clapper shell would have attained had it lived to the time of collection. The results of these calculations are shown in Fig. 11 which compares the length frequency distributions of the live scallops and the clapper shells, (adjusted for unrealized growth). It is apparent that the younger group, with a mode at about 110 mm, have a smaller clapper ratio than the group with a mode at about 132 mm. The close coincidence of the modes of the adjusted lengths of the clappers with those of the live scallops is, in our opinion, strong evidence of the reliability of this method of estimating the time of death of a clapper shell.

A sample of 236 clappers, taken in May 1960 (*Delaware* cruise 60-8) from the same unit area, was studied to determine when they had died and how long they had held together. Fig. 13 shows the results lumped into quarter-year units. The graph is similar to that of the first sample analyzed. The oldest clapper in this sample had died 14 months previously. The mean length of time clapper valves held together in this sample was 26 weeks.

In summing up it is apparent that it is possible to determine the length of time clapper valves remain together by a study of their shells. Samples of shells can be aged by using the technique of reading annual rings. The time of death of a clapper can be determined by noting the position of the shell edge in relation to the latest ring, the general condition of the ligament and shell, and the kinds and degree of fouling on them. Analysis of results using these methods show that scallops had died in all months of the year, thus discounting possibilities of sudden mass mortality. Clappers were found that had remained together for as long as 2 years.

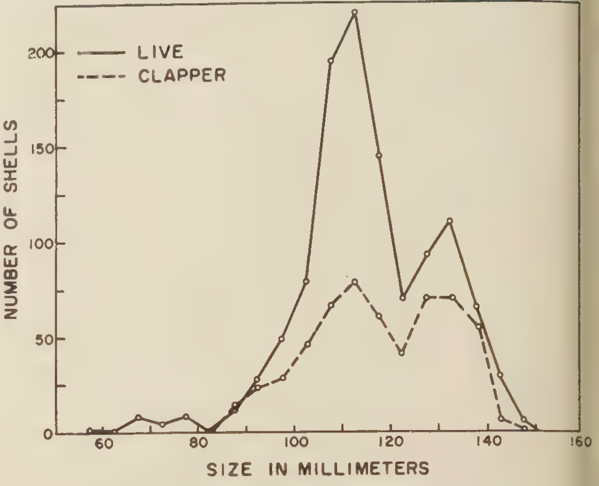
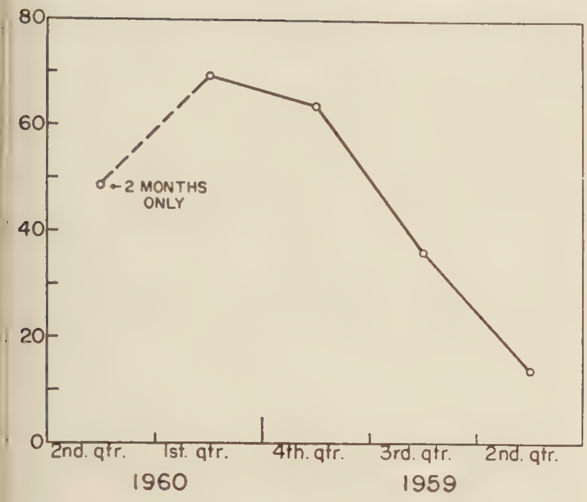


Fig. 12. Length frequency distribution of the live and clapper shells collected in August 1961 from unit area 42/66 B-6. The lengths of the clappers have been adjusted to the size that they would have attained if they had lived to the date of collection.

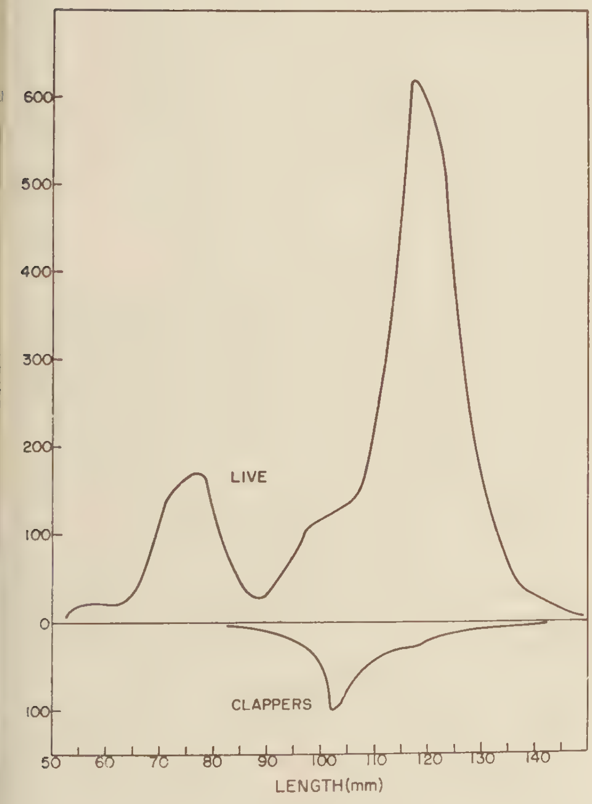
Analysis of Clapper and Live Shell Length-Frequency Distribution

The length-frequency distributions of both live and clapper shells from areas with high clapper ratios frequently show pronounced modes (Fig. 14). The modes in the clapper distribution almost always lag behind those in the live scallop distributions. This phenomenon coupled with the good agreement obtained between the live and adjusted clapper modes shown in Fig. 12, suggested that measuring the difference in length between the live and clapper modes and converting this to time using the average growth rate would give us another estimate of the time that clappers persist.

We, therefore, selected the samples shown in Table 4, located the modes, and converted the length differences to time. The average is 37 weeks. Using three different, if interrelated methods, we thus have estimates of 36, 26, and 37 weeks as the average time that clappers persist after death of the scallop; the grand average is 33 weeks.



g. 13. Dates of death for a group of clapper shells collected in May 1960 from unit area 42/66 B-6.



ig. 14. Length frequency distribution of the live and clapper shells collected in May 1961 from unit area 42/67 E-6.

Calculating the Natural Mortality Rate

Dickie (1955) in his calculations used the formula:

$$a = 1\text{-}e^{-(C/t)(1/L)(365)}$$

in which a is the annual rate of natural mortality, C is the number of clappers in the sample, t is the average time in days required for the shells of the clappers to separate, and L is the number of live scallops in the sample. The exponent above is equal to the instantaneous mortality rate, so we may write:

$$M = (C/L)\,(52/t)$$

where M is the instantaneous annual coefficient of natural mortality, C and L as above, and t the average time in weeks that the clappers persist.

We have presented above in detail the data we have available for calculating an average clapper ratio for all of Georges Bank over the years we sampled. Table 5 summarizes these data by Area Group and year. The last column gives weighting factors derived from the average density index for each Area Group over the 4 years that they are available. We have calculated a weighted average clapper ratio, an unweighted clapper ratio, and a raw clapper ratio.

Inserting the weighted average clapper ratio into the equation, we have: $M = (.0662)\,(52/33) = .1045$. The unweighted average gives a clapper ratio of .0463 and $M = .0731$. The raw clapper ratio is obtained by lumping all the collections of clapper shells and live scallops together. We have collected in all 47,811 clapper shells and 643,470 live sea scallops. This gives a raw clapper ratio of .0743 and $M = .1172$. It would appear, therefore, that in our further studies of yield of a year class under various conditions of fishing pressure we can use .10 as a reasonable value of M with a spread of about ± .02.

Causes of Natural Mortality in Adult Sea Scallops

Medcof and Bourne (in press) discuss in some detail the causes of mortality in stocks of sea scallops. They identify a number of things that can affect the well being of scallops during specific periods of their life history. In this study we make no attempt to determine the natural mortality of young scallops under 80 mm. This is because we relate clappers to live scallops and few clappers under 80 mm are to be found. In effect, we are dealing with adult scallops from about the time they enter the fishery.

Among the more important causes of natural mortality mentioned by Medcof and Bourne that would affect adult scallops are predators, parasites, semi-parasites (boring sponges and annelids) which may weaken scallops and leave them susceptible to predators, and sudden rises in water temperature which occasionally produces mass mortality. Other causes (attributed by them to *fishing* mortality) have to do with damage to scallops during dredging and handling operations. Scallops may be injured by the dredge scraping over them without actually catching them, or the turmoil in the dredge during the drag and haul may kill or injure many scallops, some of which are shoveled overboard as discards or overlooked in the trash when it is returned to the sea. A putative cause is mentioned by Medcof and Bourne: returning of refuse (empty shells and waste body parts) to the beds may "sour" the bottom or otherwise cause fouling of the beds.

On Georges Bank, sea scallop mortality due to extreme temperature fluctuations can be discounted because of the deep waters where scallops are taken. We have determined earlier, using certain clapper data (Table 3; Figs. 12, 13), that there is no evidence of mass scallop mortalities such as that discussed by Dickie and Medcof (1963) in the Gulf of St. Lawrence. We have also been unable to find any concrete evidence of predation on sea scallops. We have a fair idea of species relationship on Georges Bank for dominant species are listed each time a tow is made. The only possible predator of which we are aware is the starfish, but starfish are rather scarce on Georges Bank and they are not excessively numerous in areas with high clapper ratios. There is some boring activity by sponges and annelids on Georges Bank, but the scallop appears to be able to cope with them.

We have tested the degree to which density of sea scallops affects the clapper ratios. A regression line fitted to all the data for which a density index is available has the formula: $C/L = .0308 + .00038$ (d.i.). The slope is positive, but the correlation coefficient is only .21 so it appears that density alone is not an important factor in causing mortality. Inspection of Table 1 shows many instances of low clapper ratios in arears of high density and vice versa.

The same situation applies to fishing activity. We have correlated the clapper ratios obtained in *Delaware* cruise 61-16 with the number of day fished in each unit area sampled during the previous 9 months. The regression equation is $C/L = .0062 + .00063$ (d. f.). The correlatio coefficient is .28. Fishing activity of itsel therefore, does not seem an important cause o mortality among the uncaught scallops.

A possible explanation of the positive, a though weak, correlation of high density an heavy fishing pressure with high clapper ratio lies in the fact that high density of sea scallop attracts heavy fishing pressure by the flee Under conditions of high density, a low rate o natural mortality will still cause the formation o a large number of clapper shells. As shown above some of these clappers may persist for as long a 2 years. During this time the fleet is constantl reducing the numbers of live scallops but returnin the clapper shells that they catch to the sea When we sample the area some time later, w collect all the clappers that were formed durin the past year or so but only those live scallop that remain after heavy exploitation. The density of those that remain may still be high a compared with other areas of the Bank but w will obtain a clapper ratio that is too high becaus we do not know the density of the original stoc from which the clappers were formed.

There appears to be more than scallo density or fishing activity involved to produc high natural mortality. Probably the genera environment, the bottom structure, and th general community relationships of an area ar all involved. Unusually high clapper ratios hav been found only in Area Group 3. Here conditions are such that year classes of some strengt enter the fishery each year. Consistently, ove the years, more scallops are taken from this par of Georges Bank than anywhere else (Fig. 1 The bottom sediments are composed generall of gravel and/or medium coarse sand (Wigley 1961). Usually a good assortment of invertebrates, shell, and other debris is brought up wit the scallops. The dredge hauls with high clappe ratios usually contain a high percentage of invertebrates, particularly fouling types. The substrate is effectual for larval settlement of a kinds. Returning the shucked remains of scallop to the bottom year after year possibly helps enric the fauna of this area. For instance, in a 120 square-mile (3108 sq km) area in Area Group in 1961, over 18 million pounds (8,182 metri tons) of scallop meats were taken. The adducto muscle, which is the only meat utilized, makes u approximately one third of the body weight. Thus, two thirds of the body meat or about 36 million pounds (16,364 metric tons) of scallop waste meat were returned to the sea in this area during the year, an average of 2500 pounds per square mile (438 kg/sq km) each month. In 1961 an average of 22.5 scallops (45 shell valves) were shucked for each pound of meat yielded in Area Group 3. This means that over 800 million scallop valves were returned to the sea in this area that year as additional substrate for larval settlement.

On the other hand, when an exceptionally successful year class enters the fishery, sea scallops may also be found in large numbers elsewhere on Georges Bank. In 1959 a large year class entered the fishery in Area Group 2. The bottom sediments here are composed generally of medium and fine sand. The total invertebrate fauna was not rich in 1959 as inferred from the almost pure catches of scallops taken in the dredges. Only slightly more "trash" was recorded from hauls in 1960. In 1961, associated organisms had begun to increase and in 1962 they comprised a definite part of each haul. Significantly, in 1962 the number of clappers in Area Group 2 also was on the increase (Table 5). This suggests that an increase of invertebrates including fouling organisms may be responsible for increase in scallop mortality or vice versa.

Summary

The ratio of clapper shells to live sea scallops during the period 1958-1960 as observed in research vessel catches has been less than .10 in Subarea 5Z except for a restricted area in the northeast part of Georges Bank. Here, it was estimated at .19 in 1960 and .16 in 1961, but declined to .07 in 1962.

Two samples of clapper shells which were aged to determine the year and month of death, gave estimates of 36 and 26 weeks as the average time that clappers will persist after death from causes other than fishing. Analysis of 13 length frequency distribution samples of both live and clapper shells for the time that would have been required for a sea scallop to grow from the length at which a prominent mode occurred in the clapper distribution to the length at which a prominent mode occurred in the live distribution gave an average of 37 weeks.

Using a weighted average of the clapper ratios of .0662 and an average time required for clappers to separate of 33 weeks, it is concluded that the average instantaneous natural mortality rate of the sea scallop stocks of Georges Bank during the period of study was about .10.

Acknowledgments

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TABLE 1. Live and clapper scallops arranged by unit areas for all cruises, 1958-1963. The number of 10-minute tows, clapper ratios, and density index - when available - are also listed for each unit area.

Unit area	No. of tows	Live scallops	Clapper shells	Clapper ratio	Density index
ALBATROSS III CRUISE 113, JUNE 1958					
40 /67 C-2	1	0	0	—	
40 /67 E-1	1	0	0	—	
40 /68 F-3	1	0	0	—	
41 /66 A-6	1	0	0	—	
41 /66 B-1	1	674	0	.0000	
41 /66 C-4	1	93	0	.0000	
41 /66 D-1	3	506	3	.0059	
41 /66 D-2	9	1573	8	.0051	
41 /66 D-3	4	3950	20	.0051	
41 /66 D-4	4	4522	122	.0270	
41 /66 E-1	2	2269	48	.0212	
41 /66 E-2	19	12112	30	.0025	
41 /66 C-5	2	408	0	.0000	
42 /66 A-6	4	1936	0	.0000	
42 /66 C-6	1	1028	3	.0029	
Total	54	29071	234		
DARTMOUTH CRUISE 1, SEPTEMBER 1958					
41 /66 C-4	2	1267	39	.0308	384.5
41 /66 C-6	5	7102	57	.0803	—
41 /66 D-1	40	9469	113	.0012	143.9
41 /66 D-4	6	5391	189	.0351	631.3
41 /66 E-2	2	4489	103	.0229	1796.5
41 /68 B-6	6	5004	87	.0174	—
Total	61	32722	588		
WHALING CITY CRUISE 3, MAY 1959					
40 /67 C-1	4	7301	7	.0010	475.6
40 /69 F-2	17	3286	15	.0046	61.7
41 /66 D-3	2	1003	156	.1555	115.5
41 /66 D-4	2	778	125	.1607	56.0
41 /66 E-2	8	10671	173	.0162	410.3
41 /66 E-3	2	1653	122	.0738	281.7
41 /67 E-6	3	291	1	.0034	10.3
41 /68 B-6	8	7599	159	.0209	261.3
Total	46	32582	758		
WHALING CITY CRUISE 4, SEPTEMBER 1959					
40 /67 B-2	9	9139	16	.0018	
40 /67 C-1	8	23638	79	.0033	
41 /66 E-2	5	16010	834	.0521	
41 /68 B-6	13	6512	142	.0218	
Total	35	55299	1071		

ABLE 1. (continued)

Unit area	No. of tows	Live scallops	Clapper shells	Clapper ratio	Density index
ELAWARE CRUISE 60-8, MAY 1960					
40/67 A-2	1	191	0	.0000	49.9
40/67 B-1	1	53	0	.0000	11.3
40/67 B-2	2	333	1	.0030	47.8
40/67 C-1	6	1681	23	.0137	72.2
40/67 C-2	3	611	4	.0065	52.0
40/67 D-1	4	1371	11	.0080	81.2
40/67 E-1	1	487	3	.0062	125.5
40/68 A-1	3	399	0	.0000	73.7
40/68 D-2	1	0	0	--	0.0
40/68 E-1	2	98	0	.0000	—
40/68 F-2	1	123	3	.0244	—
40/69 F-1	2	167	1	.0060	52.8
40/69 F-2	5	846	4	.0047	36.5
41/66 B-1	2	625	37	.0592	77.4
41/66 C-1	1	139	12	.0863	35.3
41/66 D-1	1	469	1	.0021	161.0
41/66 D-2	1	307	8	.0261	124.6
41/66 D-3	1	1426	337	.2363	449.4
41/66 E-2	7	2808	341	.1214	149.5
41/66 E-3	1	500	50	.1000	173.0
41/66 F-2	1	1556	84	.0540	—
41/67 D-6	1	106	0	.0000	36.1
41/67 E-6	1	358	1	.0028	107.0
41/68 A-6	1	758	1	.0013	198.8
41/68 B-6	1	798	6	.0075	188.2
42/66 A-6	2	2002	882	.4406	196.4
42/66 B-6	3	841	259	.3080	83.1
42/67 E-6	1	0	0	—	0.0
41/67 F-6	2	2447	364	.1488	402.1
Total	58	21500	2433		
ELAWARE CRUISE 61 - 7, MAY 1961					
40/67 A-1	3	241	0	.0000	22.3
40/67 A-2	5	674	9	.0134	37.5
40/67 B-1	4	958	4	.0042	80.1
40/67 B-2	4	816	0	.0000	68.8
40/67 C-1	12	4563	122	.0267	110.2
40/67 C-2	3	642	25	.0389	41.9
40/67 D-1	5	1877	23	.0123	101.0
40/67 E-1	5	2584	1	.0000	176.0
40/67 F-1	2	635	11	.0173	91.4
40/68 B-1	1	1	0	.0000	0.3
40/68 B-2	1	22	0	.0000	5.9
40/68 B-3	1	41	0	.0000	14.7
40/68 C-3	1	11	0	.0000	3.2
40/68 E-3	1	68	0	.0000	21.2
40/68 F-1	2	112	0	.0000	29.1
40/68 F-2	1	301	0	.0000	94.2
41/66 A-1	5	432	2	.0046	46.9
41/66 B-1	4	6068	416	.0686	370.3
41/66 B-5	1	56	0	.0000	21.9
41/66 C-1	4	3403	212	.0623	185.4
41/66 C-4	1	816	35	.0429	257.0

TABLE 1. (continued)

Unit area	No. of tows	Live scallops	Clapper shells	Clapper ratio	Density index
DELAWARE CRUISE 61 - 7, MAY 1961 (Continued)					
41 /66 D-1	4	1457	668	.4585	94.3
41 /66 D-3	4	1973	214	.1085	168.1
41 /66 E-2	7	3038	784	.2581	129.3
41 /67 A-1	2	448	6	.0134	64.2
41 /67 D-1	2	517	1	.0019	78.7
41 /67 E-1	4	333	8	.0240	42.5
41 /67 E-6	1	370	3	.0081	125.4
41 /67 F-1	4	574	4	.0070	59.2
41 /67 F-6	1	53	1	.0019	14.4
41 /68 A-5	4	483	2	.0041	48.6
41 /68 A-6	6	1208	9	.0075	54.4
41 /68 B-4	2	129	3	.0233	15.2
41 /68 B-5	4	279	9	.0323	20.5
41 /68 B-6	9	966	0	.0000	39.6
41 /68 C-3	1	134	3	.0224	37.6
41 /68 C-4	6	541	8	.0148	22.2
41 /68 C-5	4	669	9	.0135	43.5
41 /68 C-6	6	627	51	.0813	30.2
41 /68 D-2	1	0	0	—	0.0
41 /68 D-3	2	15	0	.0000	2.5
41 /68 E-2	1	13	0	.0000	4.4
41 /68 F-1	2	137	0	.0000	21.9
41 /68 F-2	1	3	0	.0000	1.0
41 /69 F-6	6	452	9	.0199	17.1
42 /66 A-6	4	4146	1474	.3555	174.6
42 /66 B-6	1	89	3	.0337	23.9
42 /67 D-6	4	1641	29	.0177	128.3
42 /67 E-6	4	2906	331	.1139	251.7
42 /67 F-6	4	6650	1046	.1573	240.3
Total	167	54172	5535		
DELAWARE CRUISE 61 - 13, AUGUST 1961					
41 /66 C-1	6	295	29	.0983	23.6
41 /66 B-1	212	122341	2950	.0241	183.6
42 /66 B-6	2	1125	516	.4587	169.2
Total	110	123761	3495		
CAPE EAGLE CRUISE, SEPTEMBER 1961					
41 /66 C-1	38	9953	809	.0813	
41 /66 E-2	50	19415	3065	.1579	
42 /66 A-6	41	56864	11708	.2059	
Total	129	86232	15582		

BLE 1. (continued)

Unit area	No. of tows	Live scallops	Clapper shells	Clapper ratio	Density index
LAWARE CRUISE 61 - 16, SEPTEMBER 1961					
40 /67 A-1	4	343	0	.0000	32.5
40 /67 A-2	4	1308	1	.0008	81.3
40 /67 A-3	4	40	0	.0000	0.3
40 /67 B-1	4	874	13	.0149	45.7
40 /67 B-2	4	1104	3	.0027	60.8
40 /67 C-1	4	1857	18	.0097	79.6
40 /67 C-2	4	810	28	.0346	43.6
40 /67 D-1	4	3179	37	.0116	155.4
40 /67 D-2	4	498	10	.0201	35.1
40 /67 E-1	4	5014	14	.0028	271.6
40 /67 E-2	4	48	0	.0000	5.7
40 /67 F-1	4	2202	10	.0045	174.5
40 /68 C-2	1	175	0	.0000	42.6
40 /68 D-3	4	361	1	.0028	20.8
40 /68 E-3	4	80	0	.0000	4.9
40 /68 F-2	4	3444	2	.0006	116.5
40 /68 F-3	4	78	1	.0128	4.3
41 /66 A-1	4	1038	84	.0809	66.1
41 /66 A-6	5	231	1	.0043	31.5
41 /66 B-1	4	1378	48	.0348	123.3
41 /66 B-5	4	325	18	.0554	21.9
41 /66 B-6	4	159	7	.0440	14.2
41 /66 C-1	5	111	9	.0811	10.1
41 /66 C-2	4	64	1	.0156	5.9
41 /66 C-3	4	14	0	.0000	0.5
41 /66 C-4	4	1513	67	.0443	139.8
41 /66 C-5	4	753	150	.1992	49.0
41 /66 D-1	4	14	4	.2857	4.6
41 /66 D-2	4	539	60	.1113	31.2
41 /66 D-3	4	500	32	.0640	53.2
41 /66 D-4	4	1427	198	.1388	134.7
41 /66 E-1	5	4207	3492	.8300	280.4
41 /66 E-2	4	1294	211	.1631	70.1
41 /66 E-3	4	2031	271	.1334	140.6
41 /67 E-6	4	205	1	.0049	14.8
41 /67 F-6	4	126	1	.0079	9.8
41 /68 A-5	4	22	7	.3182	3.7
41 /68 A-6	4	353	3	.0085	36.3
41 /68 B-5	4	563	0	.0000	19.7
41 /68 B-6	5	2294	44	.0192	49.8
41 /69 C-3	2	120	3	.0250	13.9
41 /69 D-3	2	0	0	—	0.0
41 /69 E-4	2	1	0	.0000	0.1
41 /69 E-5	1	0	0	—	0.0
41 /69 F-5	3	3	0	.0000	0.3
41 /69 F-6	4	504	0	.0000	68.8
42 /66 A-6	4	3421	685	.2002	783.8
42 /66 B-6	4	943	213	.2259	57.6
42 /66 C-6	4	647	419	.6476	56.5
42 /67 E-6	4	2422	603	.2490	202.1
42 /67 F-6	4	5724	986	.1723	382.1
Total	195	54361	7756		

TABLE 1. (continued)

Unit area	No. of tows	Live scallops	Clapper shells	Clapper ratio	Density index
DELAWARE CRUISE 62 - 6, MAY 1962					
40 /67 A-1	4	176	1	.0057	12.2
40 /67 A-2	4	801	8	.0100	62.8
40 /67 B-1	4	305	13	.0426	19.9
40 /67 B-2	4	786	3	.0038	56.9
40 /67 C-1	9	6029	261	.0433	163.4
40 /67 C-2	4	286	21	.0734	21.7
40 /67 D-1	9	11797	578	.0490	205.7
40 /67 D-2	4	349	11	.0315	27.0
40 /67 E-1	9	12878	428	.0332	296.8
40 /67 F-1	4	11298	58	.0051	309.0
40 /68 A-1	4	429	1	.0023	33.1
40 /69 F-1	4	530	9	.0170	44.9
41 /66 A-1	4	20	0	.0000	1.8
41 /66 B-1	3	1902	62	.0326	144.2
41 /66 B-5	3	322	4	.0124	33.3
41 /66 C-1	4	1478	46	.0311	111.4
41 /66 C-2	4	535	7	.0131	41.5
41 /66 C-3	4	211	3	.0142	17.6
41 /66 C-4	4	1458	37	.0254	113.1
41 /66 C-5	4	797	44	.0552	75.4
41 /66 D-1	4	826	83	.1005	73.4
41 /66 D-2	4	236	7	.0297	21.5
41 /66 D-3	4	1156	24	.0208	85.7
41 /66 D-4	4	4220	172	.0408	238.2
41 /66 E-1	4	1359	393	.2891	175.5
41 /66 E-2	4	706	61	.0864	84.1
41 /66 E-3	5	4203	192	.0457	274.6
41 /67 E-6	4	113	1	.0088	9.2
41 /67 F-6	3	307	2	.0065	28.0
41 /68 A-6	4	239	4	.0167	20.4
41 /68 B-6	4	107	4	.0374	8.3
42 /66 A-6	4	3892	336	.0863	195.8
42 /66 B-6	4	2538	268	.1056	153.8
42 /66 C-6	5	2631	253	.0962	96.1
42 /66 D-6	4	1696	55	.0324	158.4
42 /66 E-6	4	2563	219	.0854	180.1
42 /66 F-6	4	2000	199	.0995	104.5
Total	162	81179	3868		
DELAWARE CRUISE 62-10, SEPTEMBER 1962					
41 /65 A-2	5	642	12	.0187	46.5
41 /66 A-1	8	366	22	.0601	24.5
41 /66 B-1	6	1929	114	.0591	90.9
41 /66 B-4	5	462	6	.0130	43.2
41 /66 B-5	6	246	5	.0203	22.2
41 /66 C-1	6	1254	68	.0542	95.1
41 /66 C-2	5	650	22	.0338	44.1
41 /66 C-3	7	557	8	.0144	25.5
41 /66 C-4	6	2551	88	.0345	137.4
41 /66 C-5	6	1254	34	.0271	81.2
41 /66 D-1	5	1382	118	.0854	96.8
41 /66 D-2	5	668	9	.0135	42.0

BLE 1. (continued)

Unit area	No. of tows	Live scallops	Clapper shells	Clapper ratio	Density index
LAWARE CRUISE 62-10, SEPTEMBER 1962 (Continued)					
41 /66 D-3	7	1409	23	.0163	58.4
41 /66 D-4	6	14112	460	.0326	392.8
41 /66 D-5	6	3224	185	.0574	102.9
41 /66 E-1	6	2904	1258	.4332	213.2
41 /66 E-2	6	1215	23	.0189	58.2
41 /66 E-3	6	6052	150	.0248	163.2
41 /66 F-1	6	1947	259	.1330	75.5
41 /66 F-2	6	2621	417	.1591	147.3
41 /66 F-3	6	2577	64	.0248	92.7
41 /67 F-1	4	112	9	.0804	12.3
42 /66 A-6	5	1992	302	.1516	90.8
42 /66 B-6	6	1659	155	.0934	114.1
42 /66 C-6	6	1291	275	.2130	72.2
42 /66 D-6	6	1524	300	.1969	66.3
42 /67 D-6	7	2711	157	.0579	108.9
42 /67 E-6	5	1881	221	.1175	85.4
42 /67 F-6	7	1670	180	.1078	100.2
Total	171	60862	4944		
BATROSS IV CRUISE 63-1, MAY 1963					
40 /67 A-2	6	940	68	.0723	47.7
40 /67 B-1	6	515	44	.0854	22.9
40 /67 B-2	6	583	22	.0377	31.2
40 /67 C-1	6	713	74	.1038	37.1
40 /67 C-2	6	409	90	.2200	19.1
40 /67 D-1	6	1836	206	.1122	110.2
40 /67 E-1	6	1525	234	.1534	91.9
40 /67 F-1	6	4422	553	.1251	224.8
40 /68 F-2	6	786	49	.0623	35.9
Total	54	11729	1340		
BATROSS IV CRUISE 63-3, JUNE 1963					
40 /68 A-1	6	630	6	.0095	23.7
40 /68 A-4	6	416	15	.0361	20.0
40 /68 B-3	6	250	5	.0200	15.1
40 /68 C-3	6	414	1	.0024	19.6
40 /69 E-1	6	161	0	.0000	7.8
40 /69 E-2	6	311	5	.0161	12.8
40 /69 F-1	6	941	5	.0053	37.7
40 /69 F-2	6	449	1	.0022	24.3
40 /69 F-3	6	197	4	.0203	8.8
41 /68 A-6	6	321	2	.0062	25.6
41 /68 B-5	7	276	1	.0036	11.4
41 /68 B-6	5	275	2	.0073	14.3
41 /68 C-6	6	596	145	.2433	28.9
41 /69 E-5	5	219	4	.0183	23.0
41 /69 F-5	6	474	9	.0190	24.9
41 /69 F-6	5	633	2	.0032	53.4
Total	94	6563	207		

TABLE 2. Average size at time of formation of the annual rings for the live sea scallops collected in August 1961 fro unit area 42/66 B - 6

Ring no.	Average size	Measurements
	mm	*no.*
1	20.2	481
2	47.0	502
3	74.6	504
4	95.7	478
5	109.8	172
6	119.6	123
7	126.5	101
8	132.0	62
9	137.3	28
10	142.2	6
11	148.4	1
12	149.8	1

TABLE 3. Clappers arranged by year classes to show how many died each month.

Month clapper died	Year Class										Total
	59	58	57	56	55	54	53	52	51	50	
August 1961			1	1							2
July		2	6	1		4	4				17
June		1	11	3	5	4	1				25
May	1	2	12	4		4	1	1			25
April		2	12	4	4	4		1			27
March	1	3	15	4	2	5	3	3	1		37
February		5	15	5	5	1	1				32
January			23	3	5	4	1	1			37
December 1960		1	10	3	5	7	1	1			28
November		2	17	7	10	4	3				43
October		3	15	9	7	9	9	2	1		55
September	1	2	12	2	4	6	1	1			29
August			5	5	5	4	1	1			21
July			7	2	2	1	3	1			16
June			3	4	5	1	1	2	1		17
May			1	2		1	2				6
April			5	3	3	3	3	3		1	21
March			4	2		2		2			10
February					2	1		1			4
January					1	2	2	2			7
December 1959				1	2	3	1	1			8
November					3		1		1		5
October				1	2		1				4
September					2	1	1				4
Total	3	23	174	66	74	71	41	23	4	1	480

LE 4. Modal lengths of live and clapper shells in samples with high clapper ratios. The last column gives the average number of weeks required for a sea scallop to grow from the length at the clapper mode to the length at the live mode

Unit area	Date	Clappers	Live	Time
		mm	*mm*	*wks*
41/66 E-2	May 1960	93.0	107.4	48
41/66 D-3	May 1960	102.1	107.4	20
42/66 A-6	May 1960	92.2	97.9	17
42/66 B-6	May 1960	97.6	107.8	37
42/67 F-6	May 1960	102.3	106.6	17
41/66 D-3	May 1961	102.9	112.6	42
41/66 E-2	May 1961	102.6	112.7	44
42/66 A-6	May 1961	97.7	106.7	32
42/67 E-6	May 1961	108.3	118.2	43
42/67 F-6	May 1961	101.9	107.0	20
41/66 D-1	May 1962	117.5	122.6	32
41/66 E-1	May 1962	93.4	112.8	69
42/66 B-6	May 1962	117.6	126.8	66

BLE 5. Summary of average clapper ratios by Area Group and year

a group	1958	1959	1960	1961	1962	1963	Average	Factor
1	.0087	.0158	.0037	.0287	.0184	.0318	.0178	14
2	—	.0024	.0045	.0017	.0298	.0851	.0247	31
3	.0102	.0757	.1895	.1616	.0727	—	.1019	55

REACTIONS OF HOSTS TO PROBOSCIS PENETRATION BY ODOSTOMIA SEMINUDA (PYRAMIDELLIDAE)

By ARTHUR S. MERRILL[1] and KENNETH J. BOSS[2]

Ectoparasitic pyramidellids occur on a wide variety of hosts (see Robertson and Orr, 1961, for review of the literature). Also documented is the fact that prolonged parasitization by pyramidellids may interfere with the normal development and growth of the host (Cole and Hancock, 1955; Loosanoff, 1956). The immediate reactions of hosts to the stimulus of proboscis penetration by ectoparasites are less well known. One of the purposes of this paper is to describe and illustrate these reactions.

The work of Cole and Hancock (1955) indicated that in the European oyster, *Ostrea edulis* Linnaeus, and in the common edible mussel, *Mytilus edulis* Linnaeus, mantle tissues are subject to considerable irritation by the penetration of the proboscides of parasitic gastropods. Constant irritation causes the withdrawal of the affected portions of the mantle and allows the ectoparasites to enter and live within the shell cavity of the host. The host often reacts by depositing a barrier of shell material, this resulting in local internal shell malformation. Cole and Hancock suggested that the oysters suffered a varying "loss of condition" and even death, depending upon the severity of attack. In general, Loosanoff (1956) reported similar effects in the American oyster, *Crassostrea virginica* (Gmelin). He further noted that the oyster soon becomes accustomed to prolonged localized parasitization and fails to close its valves even when under severe attack by several parasites at the same time.

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Observations of actual proboscis penetration by *Odostomia impressa* (Say) have been made on *Crassostrea virginica* from which one valve had been removed (Allen, 1958; Wells, 1959). We employed this method using the ectoparasite, *Odostomia bisuturalis* (Say), in an attempt to observe the reactions of *C. virginica* to penetration. We were able to note clearly the long, thin, semi-transparent proboscis of *O. bisuturalis* extending to the somewhat retracted mantle of the oyster and to see the sucking and pumping action of the proboscis. However, we failed to detect any muscular reaction by the bivalve hosts when they were pierced. This we attributed to the probability that the oysters would not react normally after recently sustaining the shock of removal of one of their valves.

In order to make observations on the immediate reaction of normal hosts to proboscis penetration, it was necessary to find host animals that could be observed uninjured. The sessile gastropods, *Crepidula fornicata* (Linnaeus), *C. plana* Say, and *Crucibulum striatum* Say were selected because the external morphological features of the animals could be observed *in situ* without direct or tactile interference by the investigators. The host animals were allowed to adhere to glass plates and the *Odostomia seminuda* (C. B. Adams) (Plate 4, fig. 1.) were introduced among them. The entire procedure was done under water in glass aquaria. With the glass plate set on edge, both dorsal and ventral views of the host animals were easily obtained.

Our observations show that in most cases the proboscis of *Odostomia seminuda* penetrated the mantle of the host (Plate 5, fig. 1), although infrequently the proboscis would extend beyond to pierce the visceral mass (Plate 4, fig. 2). In either case proboscis penetration elicited from the host an immediate muscular response. Plate 4, fig. 2 pictures the withdrawal reaction exhibited by *C. fornicata* when it was being parasitized. Figure 3, in Plate 4 taken 2 two minutes after fig. 2, illustrates the gradual subsidence of the withdrawal reaction of the host after

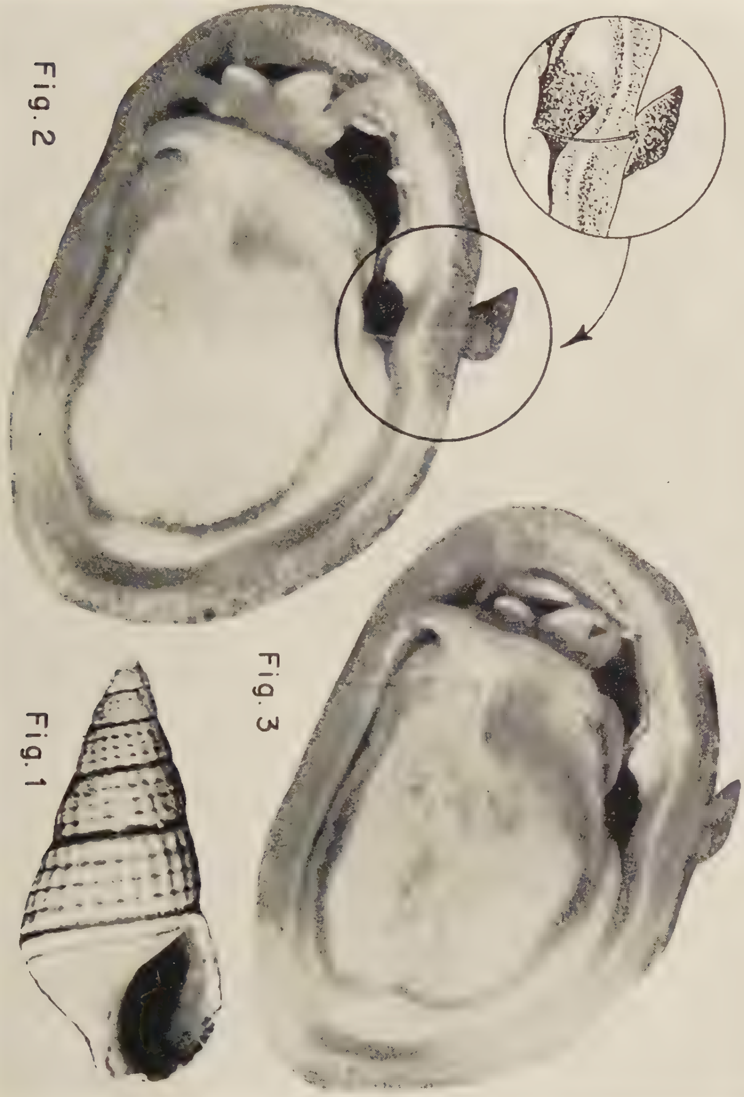

Fig. 2

Fig. 3

Fig. 1

Fig. 1. *Odostomia seminuda* (C. B. Adams) (actual length 3.7 mm). Fig. 2. Ventral view of *Crepidula fornicata* Linnaeus with associated parasites, *Odostomia seminuda*. Proboscis penetration into the visceral mass is evident. Note contracted muscles in the area of penetration (length of *Cupidula* 30 mm). Fig. 3. Ventral view of *Crepidula fornicata* (photograph taken 2 minutes after the one in fig. 2). *Crepidula* has clamped tightly to the glass plate causing *Odostomia* to withdraw its proboscis. Muscles are less contracted, especially in the mantle.

the removal of the proboscis.

Cole and Hancock (1955), Allen (1958), and Robertson and Orr (1961), reported the gathering of ectoparasites around a single host. This was noted often during this study when hosts and parasites were placed randomly on glass plates. Plate 5, fig. 1 shows the dorsal and fig. 2 the ventral view of the same animal, *Crucibulum striatum* Say, with the concentration of *Odostomia seminuda* at the shell edge. The mantle of the *Crucibulum* is withdrawn in one area where the vague outline of a proboscis can be seen penetrating into it. These two species would not be found together in the natural environment since they are bathymetrically isolated; *Crucibulum striatum* is found in deeper water. Those used in this study were dredged during "Albatross IV" cruise 63-3, station 52, Great South Channel, near Nantucket Shoals, off Massachusetts (N. Lat. 40°37′; W. Long. 69°08′), in 37 fathoms. On the other hand, *O. seminuda* were collected in shallow water, 2-4 feet deep, near the mouth of the Bass River, West Dennis, Cape Cod, Massachusetts. Under laboratory conditions the two species form this strong association, which is herein reported for the first time.

Odostomia seminuda usually move about rather freely among a clump of *Crepidula fornicata,* but at times they aggregate around a single specimen. When observed in the field, most of the ectoparasites were near, or at the edge of the host's shell Examination under a dissecting microscope showed the proboscis of *Odostomia* extending underneath *C. fornicata* in the manner described and figured by Robertson (1957). We often observed *O. seminuda* at the margin of the host but close examination showed that they were not always feeding. The peripheral interiors of several dozen shells of *C. fornicata* were inspected without finding any indication of shell malformation due to excessive parasitization of one area of the mantle. Since *C. fornicata* clamps its shell against the substrate as a reaction to the parasitization and since *O. seminuda* thereupon instantly withdraws its proboscis, there is little opportunity for extensive irritation.

We concur with Robertson (1957) that *Odostomia seminuda* feeds on *Crepidula fornicata* for only short periods at a time. A similar situation prevails in the small gastropods *Hydrobia* and *Rissoa* which are parasitized by *Odostomia scalaris* MacGillivray

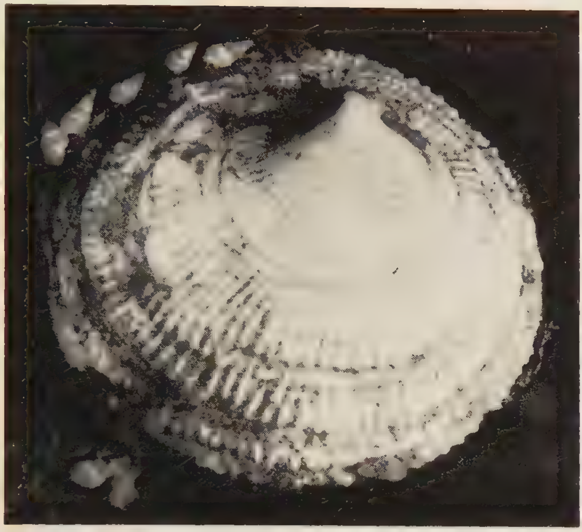

Fig. 1

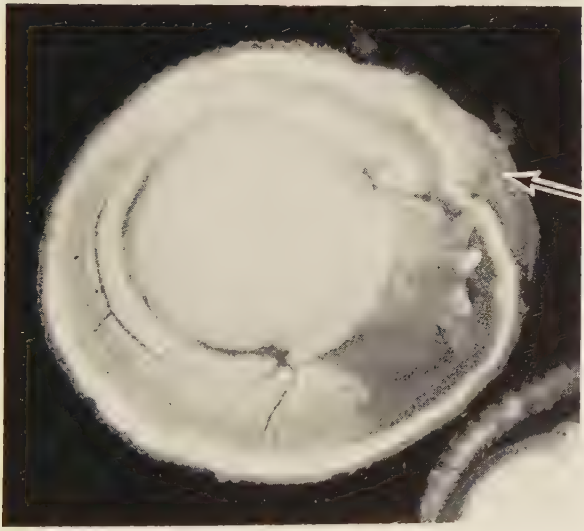

Fig. 2

Fig. 1. Dorsal view of *Crucibulum striatum* Say with a concentration of *Odostomia seminuda* C. B. Adams along the shell edge (length of *Crucibulum* 35 mm). Fig. 2. Ventral view of same animal of *Crucibulum striatum* showing the withdrawal reaction of the mantle. Note the vague outline of a proboscis (arrow) penetrating the mantle at its point of greatest withdrawal.

(= *rissoides* Hanley). According to Ankel and Christensen (1963), these hosts seldom allow the parasites to feed for periods of more than a few seconds before they retract into their shells. The persistence of the parasites enables them to be successful in their attacks on *Crepidula, Crucibulum, Hydrobia,* and *Rissoa.*

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An Aberrant Green Sturgeon From the Lower Columbia River①

An abnormal, small green sturgeon *(Acipenser medirostris)* was caught on August 7, 1957 in a salmon gill net in the lower Columbia River off Megler, Washington by Ed Hillsberry of Ilwaco, Washington.

The frozen sturgeon was 116.7 cm in total length and weighed 18.5 pounds the day after capture. It had 35 dorsal fin rays, 25 anal fin rays, 38 left pectoral fin rays, and 40 right pectoral fin rays. The fish was abnormal in three respects (none of which appeared detrimental to survival): (1) a single median fin on the ventral surface in addition to the normal ventral and anal fins; (2) an incomplete left lateral scute row which arched and became obsolete immediately posterior to the ventral fin bases; and (3) a secondary caudal fin. Location of these anomalies may be seen in Figures 1 and 2, which are tracings from photographs.

The single median fin was located immediately ahead of the anterior ventral scute on the left side; the 5 left ventral scutes were in line between the origin of the left ventral fin and the median fin. The eight ventral scutes on the right side were normal. The length of the median fin base was approximately 60% of that of the ventral fin base. The proximal half of the fin appeared leathery and had no rays, while the distal half was rayed. A small, separate rayed segment was attached to the anterior edge of the fin base.

There were 29 scutes in a normal lateral row on the right side of the fish. On the left side there were 14 normal scutes extending posteriorly from the head, followed by 3 small scutes in a row arching dorsally. Three additional very small scutes formed a separate row ventral to the lateral row and directed posteriorly from a position above the ventral fin base.

The fish had a smaller secondary caudal fin in addition to a normal heterocercal caudal fin. The secondary caudal had a rounded rather than pointed dorsal lobe; it originated on the left side of the caudal peduncle and for more than half its length was joined ventrally to the normal caudal.

Morphometrics are given in Table 1.

The aberrant sturgeon was unfortunately lost in an attempt to dry it and could not be X-rayed to determine if the deviations stemmed from an injury.

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① Contribution No. 69, U. S. Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Georgia.

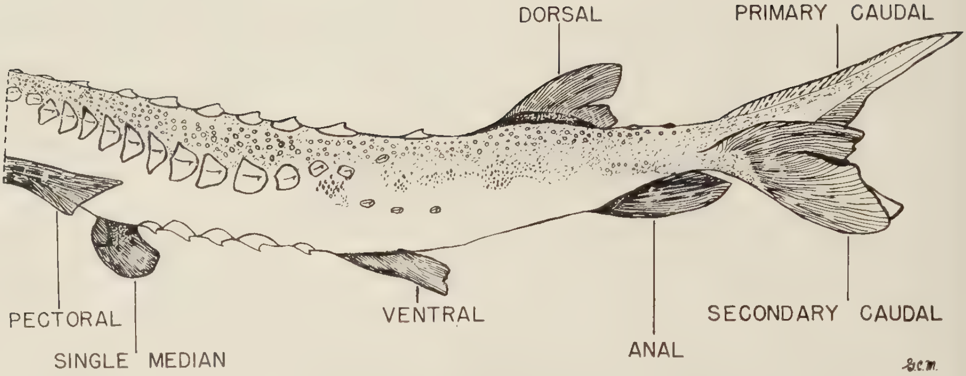

FIGURE 1. LEFT LATERAL VIEW OF THE BODY OF AN ABNORMAL GREEN STURGEON POSTERIOR TO THE PECTORAL FIN.

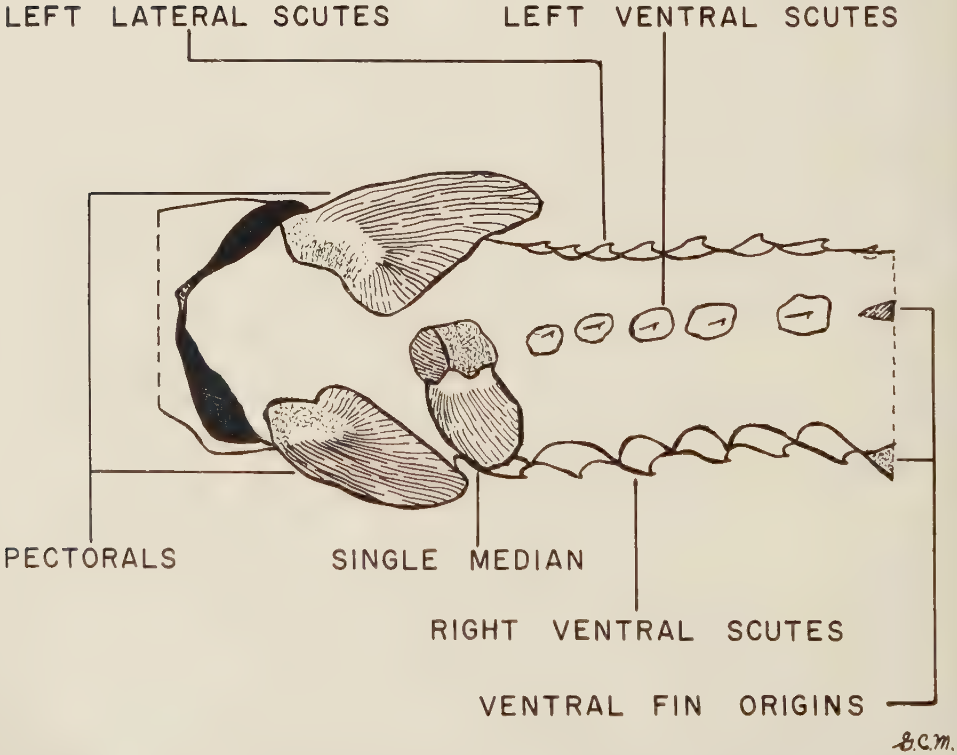

FIGURE 2. VENTRAL VIEW OF A PORTION OF AN ABNORMAL GREEN STURGEON.

TABLE 1. **MORPHOMETRICS FROM AN ABNORMAL GREEN STURGEON.**

Length From Tip of Snout to:	*Millimeters*
Barbel origins	52
Anterior edge of nostrils	63
Anterior edge of mouth	90
Edge of opercle	95
Pectoral fin	233
Median fin	382
Pelvic fin	620
Anterior edge of anus	660
Dorsal fin origin	743
Anal fin origin	830
Primary caudal fin origin	930
Primary caudal fin fork	1,055
Primary caudal fin tip (Total length)	1,167
Secondary caudal fin origin	910
Secondary caudal fin fork	1,063
Secondary caudal fin tip	1,080
Point of separation of caudal fins on ventral surface	1,040

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Age and Growth of the Round Whitefish in Lake Michigan

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Age and Growth of the Round Whitefish in Lake Michigan[1]

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ABSTRACT

The round whitefish, though rarely abundant, is widely distributed in northern waters. It is one of the least studied of the coregonines; the present report is but the second for Great Lakes waters. Commercial production in Lake Michigan has been tightly confined to the northern portion. The period 1924–30 showed the best production: 200,000 to 359,000 pounds. Since 1956, production has been around 10,000 pounds or less. The present age and growth study is based on 208 fish collected by gill net in December 1951. The relation between total length in inches (L) and the weight in ounces (W) is described by the equation $\log W = -2.7232 + 3.2940 \log L$. Age-group III made up 66.3 percent, and age-group IV, 20.6 percent of the sample; age-groups V, VI, and VII combined contributed only 5.9 percent. The average length for all fish in the sample was 14.5 inches. Growth was calculated from a previously published linear body-scale relation with an intercept of 1.1 inches on the axis of fish length. The increments of calculated length declined steadily from a maximum of 4.6 inches the first year to 1.0 inch the eighth. A 3-year-old Lake Michigan fish (12.3 inches) is as long as a 5-year-old Lake Superior fish, and an 8-year-old Lake Michigan fish (18.9 inches) is 0.9 inch longer than the oldest (12 years) from Lake Superior. The smallest mature males and females were in the length intervals 12.0–12.4 inches and 13.0–13.4 inches, respectively. All males over 1.4 inches and all females over 14.9 inches were mature. The youngest mature males were in age-group II; 36 percent of II-group males but none of the females were mature. All fish older than age-group III were mature.

INTRODUCTION

Such coregonine species as the lake whitefish, *Coregonus clupeaformis*, the lake herring or cisco, *Coregonus artedii*, and the various chubs, *Coregonus* spp., have received considerable study in the Great Lakes region. The mountain whitefish, *Prosopium williamsoni*, was studied by McHugh (1941) in western Canada and by Sigler (1951) in Utah, and the pygmy whitefish, *Prosopium coulteri*, was investigated in Lake Superior by Eschmeyer and Bailey (1955). The literature contains little mention of the round whitefish, *Prosopium cylindraceum*. The first report on the growth of the round whitefish in the Great Lakes is a recent one by Bailey (1963) for Lake Superior. The present study is the first for Lake Michigan.

Greene (1935) described the range of the round whitefish in North America as ". . . . southward to Lakes Superior and Michigan and thence eastward to Maine. It is widely though not abundantly distributed in northern waters. Probably this species, in common with other members of the coregonids, followed the retreat of the ice closely in its postglacial dispersal."

Commercial production of round whitefish in Lake Michigan has been rather tightly confined to the northern portion. Statistics on early catches are scattered, but continuous annual production records started in Michigan in 1911 and Wisconsin in 1917. The species has never been reported as caught by commercial fishermen of Illinois or Indiana. The production figures of the following paragraph are from data given by Baldwin and Saalfeld (1962).

Production was generally high in the early fishery. Although the erratic variability of some of the earlier Wisconsin production figures from 1917 to the late 1920's gives cause for suspicion as to completeness, some years clearly were excellent. The trends for the lake as a whole are brought out by the following records of mean annual catch by selected periods: 1893–1908 (4 years of data), 345,000 pounds; 1917–23, 112,571 pounds; 1924–30, 248,714 pounds; 1931–42, 90,500 pounds; 1943–52, 126,300 pounds; 1953–60, 13,375 pounds. The production varied, of course, within each period. The maximum catches of record were 519,000 pounds in 1899 and 423,000 pounds in 1893, both years before the start of continuous statistics. In 1917–60, the highest take was 359,000 pounds in 1929. The lowest production has been in recent years. The take has not exceeded 10,000 pounds since 1956. State of Michigan catches of the modern period, starting in 1917, have been about 2 to 5 times as great as the Wisconsin catches; only in 1920, 1952, and 1953 did Wisconsin outproduce Michigan.

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[1] A contribution from the Wisconsin Conservation Department and the Bureau of Commercial Fisheries Biological Laboratory, Ann Arbor, Michigan.

MATERIALS AND METHODS

The entire sample for this study consisted of 212 round whitefish taken from a lift of a commercial gill net on December 13, 1951. The net was 2,500 feet long, and the mesh sizes ranged from 2½ to 2⅞ inches, stretched mesh. The net was set in Lake Michigan just north of the Sturgeon Bay Ship Canal, Door County, Wisconsin, in 4 fathoms of water and fished for 3 nights. In addition, 4 fish 9.0–9.5 inches long collected from a small-meshed pound net set in the same general region in June 1951 are included in the length–weight data.

Total lengths from the tip of the snout to the tip of the caudal fin with lobes compressed were measured to the nearest 0.1 inch. Weights were determined by a spring balance and read to the nearest 0.25 ounce. The condition of sex organs of all fish was recorded. As spawning had recently taken place and all fish were opened at the time the sample was taken, accurate determination of sex and maturity was assured.

Scales were taken from the area midway between the lateral line and the anterior part of the base of the dorsal fin. Scale impressions were made in cellulose acetate and examined at a magnification ×43. Diameters of projected images of the scales and of growth fields within annuli were measured to 0.1 inch along a line passing through the focus and bisecting the anterior field.

The validity of age determinations from scales of various coregonines has been established by Van Oosten (1923), Van Oosten and Hile (1949), and Hile (1936). Sigler (1951) showed the method to be valid for the mountain whitefish. In view of the extensive evidence for other coregonines, it has been assumed the method is valid for the round whitefish.

Age groups are designated by Roman numerals corresponding to the number of annuli present. The sample of round whitefish in this study was taken on December 13, at which time growth for the year is assumed to have been completed. The number of growing seasons completed by each of the fish is therefore one greater than the number of annuli.

Some difficulty was experienced in measuring scales of fish from age-group V and older, where the annuli were poorly defined in the posterior field. Only 4 fish were discarded as totally unreadable: these because of scale regeneration.

It was not possible with the data on hand to determine a body–scale relation for the Lake Michigan round whitefish. Calculation of length from scale measurements was first made by direct proportion. It appeared that the calculated growth for the early years of life was considerably in error. Lengths were recalculated according to the body–scale relation determined by Bailey (1963) for round whitefish from Lake Superior. Bailey found the relation to be linear with an intercept of 1.1 inches on the axis of fish length. The scale samples from the Lake Superior fish were removed from a position slightly posterior to the location of samples from Lake Michigan fish, but it is questionable whether the small difference would affect materially the estimation of the intercept value.

AGE AND LENGTH AT CAPTURE

Gill nets have their maximum catching efficiency over a relatively short length range and do not take large numbers of longer or shorter fish. The smallest fish caught by the 2½- to 2⅞-inch meshes were in the 11.5- to 11.9-inch interval, and the largest fish was 20.6 inches long (Table 1).

Gear selectivity undoubtedly accounted for the absence of any round whitefish of age-group I, and no doubt only the larger fish of age-group II were captured. The length ranges of the well-represented succeeding age groups suggest that they were reasonably well

TABLE 1.—*Distribution of total length of age groups of round whitefish from Lake Michigan*

[Based on length at time of capture]

Length interval (inches)	Age group II	III	IV	V	VI	VII	Total
11.5–11.9	5	----	----	----	----	----	5
12.0–12.4	8	1	----	----	----	----	9
12.5–12.9	1	2	----	----			3
13.0–13.4	1	8	----	----	----	----	9
13.5–13.9	----	31	----	----	----	----	31
14.0–14.4		56		----	----		56
14.5–14.9		32	3	----	----		35
15.0–15.4		8	17	----	----	----	25
15.5–15.9	----	----	17	----	----	----	17
16.0–16.4	----	----	5		----	----	5
16.5–16.9	----	----		2	----	----	2
17.0–17.4	----	----	1	1	----		2
17.5–17.9	----	----		----	----	----	----
18.0–18.4	----	----		1	1		2
18.5–18.9	----	----		1	----	----	1
19.0–19.4	----	----			----	3	3
19.5–19.9	----	----		----	----	1	1
20.0–20.4	----	----		----	----	1	1
20.5–20.9		----			----	1	1
Number of fish	15	138	43	5	1	6	208
Percentage of total	7.2	66.3	20.6	2.4	0.5	3.0	100.0
Average length	12.2	14.2	15.5	17.4	18.3	19.6	14.5

sampled—12.0–15.4 inches for age-group III; 14.5–17.4 inches for age-group IV; and 16.5–18.9 inches for age-group V. The strong predominance of age-group III over older fish probably reflects conditions in the stock, not gear selection.

The overlap of age groups was limited. The greatest overlap was 1.5 inches, at 12.0–13.4 inches, between age-groups II and III. Elsewhere the overlap did not exceed 1.0 inch. No 0.5-inch interval included fish belonging to more than two age groups.

The principal contributor by far to this sample was age-group III (1948 year class), which made up 66.3 percent of the total. Age-group IV was the next most abundant group (20.6 percent), and age-groups V, VI, and VII combined made up only 5.9 percent. Age-group II (7.2 percent) doubtless would have included many more fish if the net had been able to sample it effectively.

The average lengths at capture for the various age groups are not discussed because better data on growth are given in a later section. The average length for the entire sample was 14.5 inches. The average age (mean number of annuli) was 3.31. Since it can be assumed safely that the current-season growth was completed at capture, the age in terms of completed growing seasons was 4.31.

LENGTH–WEIGHT RELATION

The records of average weights of male and female round whitefish in Lake Michigan (Table 2) indicate a small advantage for the females. They were the heavier by 0.1 to 0.8 ounce in all intervals in which both males and females were represented by 5 or more fish, and they usually outweighed the males at the less well represented lengths. In the main, however, the sex difference was not large.

It is to be remembered that this sample of fish was taken shortly after the spawning

TABLE 2.—*Length–weight relation of round whitefish from Lake Michigan*

Total length (inches)[1]	Male		Female		Sexes combined		
	Number of fish	Weight (ounces)	Number of fish	Weight (ounces)	Number of fish	Weight (ounces) Empirical	Calculated
9.2	----	------	----	------	4	3.0	2.9
9.7	----	------	----	------	----	------	3.4
10.2	----	------	----	------	----	------	3.9
10.7	----	------	----	------	----	------	4.7
11.2	----	------	----	------	----	------	5.4
11.7	2	6.0	3	6.5	5	6.3	6.3
12.2	7	7.4	2	7.5	9	7.4	7.2
12.7	3	7.8	1	8.5	4	8.0	8.1
13.2	7	8.9	2	9.5	9	9.0	9.3
13.7	27	9.9	5	10.7	32	10.0	10.5
14.2	34	11.2	23	11.7	57	11.4	11.8
14.7	13	12 7	22	12.8	35	12.8	13.3
15.2	10	14.4	15	14.8	25	14.6	14.8
15.7	5	16.2	13	16.5	18	16.4	16.5
16.2	2	17.5	3	17.5	5	17.5	18.2
16.7	----	------	2	21.5	2	21.5	20.1
17.2	1	21.0	1	20.5	2	20.8	22.2
17.7	----	------	----	------	----	------	24.4
18.2	1	27.5	1	28.0	2	27.8	26.7
18.7	----	------	1	30.0	1	30.0	29.2
19.2	2	33 3	1	32.0	3	32.8	31.9
19.7	----	------	1	36.5	1	36.5	34.7
20.2	1	38.0	----	------	1	38.0	37.7
20.7	----	------	1	40.0	1	40.0	40.9

[1] Midpoints of 0.5-inch intervals.

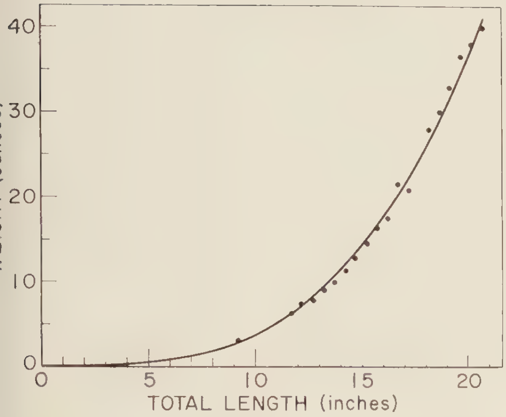

FIGURE 1.—Length–weight relation of round white-ish from Lake Michigan. The curve represents the alculated weights and the dots the empirical weights.

eason. Not only do whitefish reach maxi-um condition in early fall and decline dur-ng the winter, but this group had lost addi-ionally the weight of recently expended sex roducts. Samples of weights at various times f the year would be necessary to establish ore dependable data on the length–weight elation.

The mathematical relation between the total ength in inches (L) and the weight in ounces W), data for the sexes combined, is de-cribed by the equation $\log W = -2.7232 +$ .2940 $\log L$, which was derived by fitting a traight line to the logarithms of length and veight. The curve of this equation is shown n Figure 1 and the calculated and empirical veights are compared in Table 2. The agree-nent of weights was good except at certain engths represented by few fish.

If the minimum desirable weight of 1 pound s assumed for the Lake Michigan round vhitefish, the corresponding length is about 15.6 inches; the round whitefish attains 1.5 pounds at about 17.7 inches and 2 pounds at over 19.2 inches. Since the highly palatable flesh of round whitefish is often accepted as a substitute for the lake whitefish, a marketing weight of 1.5 to 2 pounds would be very desirable. The present sample included few of these larger round whitefish. Whether this lack of larger fish is the result of intensive fishing or of a relatively short life span is not known.

The slope of the logarithmic line describing the length–weight relation of Lake Michigan round whitefish (3.2940) is slightly greater than the slope of 3.2231 determined by Bailey (1963) for the round whitefish of Lake Superior. According to Sigler (1951), the weight of mountain whitefish increases almost exactly as the cube of the length, and the sexes exhibit no differences in the length–weight relation.

CALCULATED GROWTH

Records for individual age groups showed only limited and randomly distributed sex differences in growth. The data of Table 3, therefore, are based on males and females combined.

The calculated lengths for the age groups give no evidence of Lee's phenomenon of decrease of growth rate with increase in the age of the fish for which lengths are computed. On the contrary, such trend as exists is toward an increase of calculated length with increase of age. The calculated lengths for the first 3 years of life exhibit little change with increase of age. The tendency toward higher calculated lengths as age increases becomes detectable for the fourth year of life and persists in

ABLE 3.—*Calculated total length at end of each year of life of round whitefish from Lake Michigan*

[Asterisks indicate length at capture]

Age group	Number of fish	Length (inches) at end of year							
		1	2	3	4	5	6	7	8
II	15	4.9	9.3	12.1*	------	------	------	------	------
III	138	4.7	9.0	12.2	14.2*		------	------	------
IV	43	4.1	9.0	12.2	14.3	15.5*	--	------	------
V	5	4.3	9.1	13.2	15.3	16.5	17.5*	--	------
VI	1	4.4	9.8	13.5	15.4	16.7	17.7	18.3*	--
VII	6	4.8	9.4	12.4	14.9	16.3	17.7	18.7	19.7*
rand average calculated length		4.6	9.0	12.3	14.2	15.7	17.6	18.7	19.7
ncrement of average		4.6	4.4	3.3	1.9	1.5	1.9	1.1	1.0
rand average increment of length		4.6	4.4	3.3	2.0	1.3	1.2	1.1	1.0
um of average increments		4.6	9.0	12.3	14.3	15.6	16.8	17.9	18.9

TABLE 4.—*Calculated growth in length and weight of round whitefish from Lake Michigan*

[Lengths based on summation of grand average annual increments; data from Table 3. Weights computed from the general length–weight equation]

Year of life	Total length (inches)		Weight (ounces)	
	Average	Increment	Average	Increment
1	4.6	4.6	0.4	0.4
2	9.0	4.4	2.6	2.2
3	12.3	3.3	7.4	4.8
4	14.3	2.0	12.0	4.6
5	15.6	1.3	16.1	4.1
6	16.8	1.2	20.5	4.4
7	17.9	1.1	25.3	4.8
8	18.9	1.0	30.3	5.0

the sixth through the seventh years of life.

The discrepancies among the calculated lengths of Table 3 cannot be attributed to the use of a body–scale relation derived for round whitefish of Lake Superior and of unproven validity for Lake Michigan fish. Lengths calculated by direct proportion (data not given here), the most widely employed procedure for coregonines, exhibit discrepancies that closely paralleled those of Table 3.

Two estimates of general growth in length—the grand average calculated lengths, and the summation of the grand average annual increments of length—gave almost identical results through the first 5 years of life. The relatively fast growth of age-groups V–VII, however, caused the grand average lengths to be greater by 0.8 inch in years of life 6–8. The advantages of grand average increments for the description of growth and the small numbers of fish (1 to 6) in the three oldest age groups led to the choice of the sum of the increments for the description of the growth of round whitefish in Lake Michigan (Table 4 and Figure 2).

Increments of length for the first and second years of life were similar (4.6 and 4.4 inches). The increments decreased substantially over the next 3 years: from 4.4 inches in the second to 1.3 in the fifth. The consistent decrease of 0.1 inch per year kept the increments for years 5 through 8 within a narrow range (1.3 to 1.0 inches). The round whitefish reached a length of 12 inches near the end of the third growing season, and reached 15 inches near the middle of the fifth year. Over 7 years were required to attain a length of 18 inches.

The calculated growth in weight of the Lake Michigan round whitefish was determined by applying the calculated lengths of Table 3 to the length–weight equation previously given. The annual increment was 0.4 ounce the first year of life, 2.2 ounces the second, and then varied from 4.1 to 5.0 ounces for years 3 through 8. A fish was 5 years old before it attained the weight of 1 pound and slightly under 7 years old when it reached 1.5 pounds.

GROWTH OF ROUND WHITEFISH IN LAKES MICHIGAN AND SUPERIOR

Round whitefish from northwestern Lake Michigan had a decided advantage over two

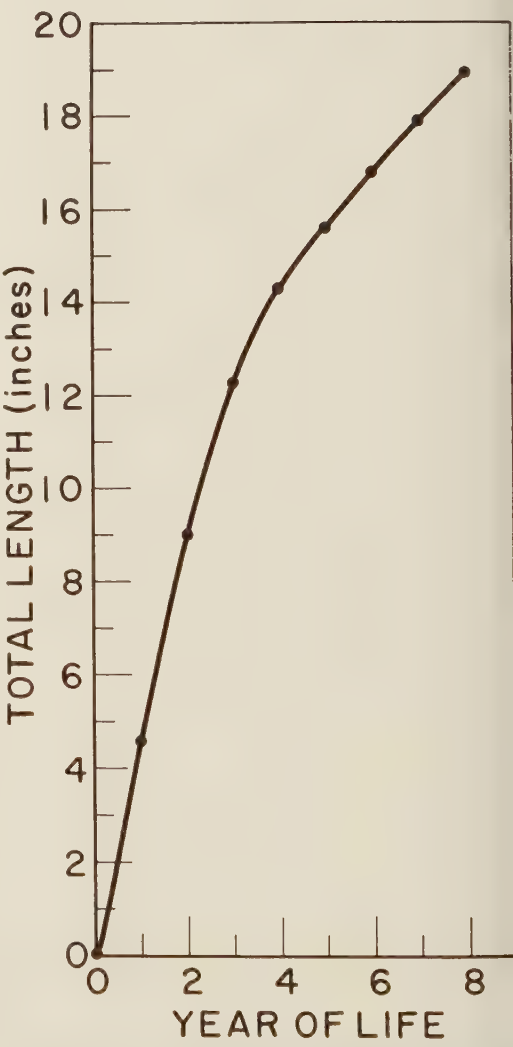

FIGURE 2.—Calculated growth in length of roun whitefish from Lake Michigan.

TABLE 5.—*Calculated growth in length and weight of round whitefish from Lake Michigan and two localities of Lake Superior*

[Data for Lake Superior round whitefish from Bailey (1963)]

Year of life	Total length (inches)			Weight (ounces)		
	Lake Superior		Lake Michigan	Lake Superior		Lake Michigan
	Apostle Islands	Isle Royale		Apostle Islands	Isle Royale	
1	4.6	3.4	4.6	0.4	0.1	0.4
2	7.2	6.0	9.0	1.5	0.8	2.6
3	9.1	8.3	12.3	3.1	2.3	7.4
4	10.8	10.3	14.3	5.4	4.7	12.0
5	12.1	12.1	15.6	7.9	7.9	16.1
6	13.1	13.4	16.8	10.1	10.9	20.5
7	14.0	14.4	17.9	12.6	13.8	25.3
8	14.8	15.3	18.9	15.0	16.7	30.3
9	15.5	16.0	------	17.4	19.3	
10	------	16.8	------	------	22.6	------
11	------	17.3	------	------	24.8	------
12	------	18.0	------	------	28.2	

Lake Superior stocks in both calculated length and weight in every year of life beyond the first (Table 5).

Lake Michigan fish were 1.8 inches longer than Apostle Islands round whitefish at the end of 2 years. This difference increased in each succeeding year of life but the fifth: to a maximum of 4.1 inches at the end of 8 years, when the respective calculated lengths were 18.9 and 14.8 inches. The advantage of Lake Michigan fish over those from Isle Royale was 3.0 inches at the end of 2 years and 4.0 at the end of 3 and 4; the differences were slightly less the next 4 years when they varied within the narrow range of 3.4 to 3.6 inches.

Differences between the calculated weights of round whitefish from the two lakes were even more striking. The Lake Michigan fish were 1.1 ounces heavier than Apostle Islands fish at the end of 2 years of life, and they increased that advantage each year to a maximum of 15.3 ounces at the end of 8 years. The weights of Lake Michigan round whitefish at the end of 7 and 8 years (25.3 and 30.3 ounces) were twice the corresponding weights for the Apostle Islands stock (12.6 and 15.0 ounces). The Lake Michigan fish outweighed the Isle Royale stock by 1.8 ounces at the end of 2 years, and increased the advantage consistently to a maximum of 13.6 ounces at the end of 8 years (Lake Michigan, 30.3 ounces; Isle Royale, 16.7 ounces).

The minimum acceptable market weight of 1 pound, set arbitrarily for Lake Michigan round whitefish, was reached by that stock in 5 years. Isle Royale fish needed almost 8 years, and the Apostle Islands stock well over 8 years to reach the same weight. It was probably the slow growth of Lake Superior round whitefish that led Bailey (1963) to set the more modest "practical" commercial size of 14 inches, total length. This size was attained by Lake Superior fish in 7 years or slightly less, and by Lake Michigan fish in a little under 4 years.

TABLE 6.—*Relation of total length (inches) and sexual maturity of round whitefish from Lake Michigan*

[All fish shorter than 12.0 inches were immature; all fish longer than 14.9 inches were mature]

Length	Males			Females		
	Number immature	Number mature	Percentage mature	Number immature	Number mature	Percentage mature
12.0–12.4	4	3	42.8	2	0	0.0
12.5–12.9	1	2	66.7	0	0	----
13.0–13.4	0	7	100.0	1	1	50.0
13.5–13.9	4	22	84.6	1	4	80.0
14.0–14.4	4	29	87.8	4	19	82.6
14.5–14.9	0	13	100.0	1	21	95.4

SEX RATIO AND MATURITY

The sample of 212 fish consisted of 97 females and 115 males (55 percent males). The spent condition of 79 of the 85 mature females (the remaining 6 were ripe) proved that most of the spawning had taken place prior to the December 13 collection date. No fish smaller than 12.0 inches was mature, and all fish 15 inches long or longer were mature (Table 6). The smallest mature males were in the size interval of 12.0–12.4 inches, and the smallest mature females were 13.0–13.4 inches long. All males over 14.4 inches and all females over 14.9 inches were mature.

Because the sample contained no fish of age-group I, it is not known if maturity occurs in fish younger than age-group II. Thirty-six percent of the II-group males but none of the fe-

TABLE 7.—*Relation between age and sexual maturity of round whitefish from Lake Michigan*

[No I-group fish in the sample; all fish older than age-group III were mature]

Age group	Males			Females		
	Number immature	Number mature	Percentage mature	Number immature	Number mature	Percentage mature
II	7	4	36.4	4	0	0.0
III	4	78	95.2	8	48	85.7

males were mature. All round whitefish older than age-group III were mature (Table 7).

Bailey (1963) reported that the Lake Superior round whitefish were mature as small as 7.0–7.4 inches, and that the youngest mature fish belonged to age-group II. He also showed that all fish larger than 12.9 inches (with one dubious exception) were mature. Males older than age-group IV (with the same single exception) and females older than age-group V were all mature. These differences in both size and age at maturity possibly can be explained by the large differences of growth rate in the two lakes.

ACKNOWLEDGMENTS

The materials and data for this study were collected while I was employed at the Sturgeon Bay, Wisconsin, field station of the U.S. Bureau of Commercial Fisheries Biological Laboratory of Ann Arbor, Michigan, and analyzed during my employment with the Wisconsin Conservation Department. These two agencies have long conducted research cooperatively in Green Bay areas. Merryll M. Bailey permitted me to examine the manuscript of his 1963 paper prior to its publication. Ralph Hile reviewed and criticized the manuscript.

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25. A METHOD OF MEASURING VISUAL ACUITY OF SCOMBRIDS

Development of techniques for capturing tunas and maintaining them in captivity has progressed sufficiently to allow subjection of these pelagic scombrids to experimental procedures. Experiments designed to measure the visual acuity of tunas have been developed recently at the U. S. Bureau of Commercial Fisheries Biological Laboratory in Honolulu.

The method involves training a fish to respond in a desired manner when a visual stimulus is presented. The visual stimulus is an image of either vertical or horizontal stripes which is projected onto an opal glass plate placed against a window of the tank. When the stripes are vertical, the fish is trained to swim down the tank to a food-drop area where it is rewarded. When the stripes are horizontal, the fish is trained to turn before it reaches the food-drop area and return to the far end of the tank. If it fails to turn around when horizontal stripes are presented, the fish receives an electric shock. The image is projected onto the opal glass plate when the fish is at the far end of the tank. The projector is turned off when the fish reaches a marked distance from the window. Filters are used to reduce the illumination of the striped image until the fish is no longer able to discriminate between vertical and horizontal stripes.

Visual angles are computed from measurements of the width of the stripes and of the distance between the fish's eyes and the striped image. Visual acuity is calculated by taking the reciprocal of the visual angle and is then plotted against the logarithm of the luminance of the image.

The experimental tank is enclosed in a Quonset hut so that lighting can be controlled. The observer, conducting the experiment from a booth so that he cannot be seen by the fish, uses remote control buttons to operate the projector, slide changer, and electric shocker. Food is dropped from a feeding tube attached to the booth.

Preliminary analysis of the data indicates a greater visual acuity for aku, *Katsuwonus pelamis,* than for kawakawa, *Euthynnus yaito,* at higher luminances. At lower luminances, the visual acuities of the two species of tunas are similar.

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1964. /Abstract/ Proceedings of the Hawaiian Academy of Science. 39th Annual Meeting, 1963-1964, p. 26-27.

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Limnology in North America. *By David G. Frey, Editor, University of Wisconsin Press, Madison. 1963. 734 pp., Illus. $8.50.*

This volume is divided into 26 chapters, each written by authors expert in the limnology of the region or subject covered in the individual chapters. Chapter 1 gives the history of limnology in North America with particular reference to the Birge-Juday era. Chapters 2 through 20 cover geographical areas from Panama and the West Indies to the far northern areas of North America. The remaining six chapters deal with reservoirs, farm ponds, paleolimnology, sanitational limnology, the history of the American Society of Limnology and Oceanography, and future prospects.

The authors attempt to review the significant work that has been done, describe the limnological resources of each region, and at least by inference, suggest directions that further limnological research might take. These objectives have been realized quite adequately.

Inasmuch as the chapters were individually prepared, they differ considerably in format, style, and general content. Amounts of descriptive material on the limnology of the regions and the flora and fauna vary, as well as the attention given to reference material. As the literature is so vast, it would not be possible to provide full treatment to the subject of limnology in this volume. For example, fishery research and management are considered as somewhat peripheral to limnology in this presentation. However, nearly half of the authors place considerable emphasis on fisheries while several others cite the more important fishery publications, or mention the organizations engaged in fisheries work.

The section on reservoirs would have been improved if more attention had been given to a review of the literature. Although few references were cited in this section, the reader can obtain much additional material on reservoirs by referring to the regional sections. In another instance, the section on sanitational limnology contains no reference to the changes that have occurred in water quality and the biological environment of Lake Washington at Seattle and in Lake Erie as a result of increases in nutrient income. Fortunately, these lakes are covered in the regional sections. Thus, for the reader to obtain more complete coverage of the special topic chapters he should consult the index. It was found very useful, although incomplete in some respects.

I thought it very appropriate to include a section on the history of the American Society of Limnology and Oceanography. This was ably done by George H. Lauff. In his concluding statement he says, "Parallel with the growth of aquatic science, the Society must assist in establishing effective mechanisms for the collection and distribution of pertinent information of interest to its membership and must provide the direction and stimulus which will permit aquatic research to reach its full potential." This is a worthy objective for a Society that has already done much toward this end.

In the concluding section, G. E. Hutchinson explores some of the directions in which research may be profitably pursued in the immediate future. This should provoke much thought among leaders of limnological programs and provide some stimulation toward filling in our gaps of knowledge.

Limnologists, oceanographers, and fishery biologists will find this volume a valuable addition to their libraries. In content and physical make-up it is of high quality. If the National Science Foundation had not subsidized the work, this volume would have sold for much more than the $8.50 price. Many biologists otherwise would not have been able to afford a personal copy. The Foundation is to be congratulated for this wise use of its funds.

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esapeake Science Vol. 5, No. 3, pp. 145–149 Fall, 1964

rowth Compensation in Four Year Classes of triped Bass, *Roccus saxatilis*, from lbemarle Sound, North Carolina

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ABSTRACT: Compensatory growth, the tendency of smaller individuals to catch up with larger individuals, was measured by linear regression coefficients for four year classes of striped bass, *Roccus saxatilis* (Walbaum), from Albemarle Sound, North Carolina. Samples were obtained annually from late October to March, 1955–1958. Annual scale growth was used as a measure of annual linear body growth. Compensatory growth was shown to occur in year 2 and year 3 when compared with growth in year 1, and in year 3 when compared with growth in year 2. There was no significant difference in the amount of compensatory growth among the four year classes studied.

Introduction

Compensatory growth is the tendency of ndividuals that grow less than the average n one year to grow more than the average n the following year or years. When growth ompensation occurs, the regression of the rowth increment in one year on that of a revious year is negative.

Previous workers were concerned mainly vith demonstrating the occurrence or nonccurrence of compensatory growth, rather han with trying to measure the statistical ignificance of the coefficients or compare he variation that occurs. In most studies, ompensatory growth in years 2, 3, or 4 was ompared with the size attained at the end f year 1. Van Oosten (1928) reported ompensatory growth in lake herring, *oregonus artedi*, in years 2, 3, and 4, and ited the work of others who found this henomenon common in year 2 for different pecies. Hile (1936) also reported compenatory growth in year 2 for lake herring. iller (1943) found growth compensation in ear 2 for striped bass from both Chesaeake Bay and the Hudson River. Scott 1949), studying the growth of rock bass n Indiana, took samples of a single year class for three successive years, and regressed the growth increments in the second through fifth years on the lengths at the end of each previous year. Ricker (1958) has a brief discussion of this phenomenon and also lists some additional references.

Compensatory growth may be determined by comparing growth increments in two different years by either correlation or regression analysis. Since growth in one year is assumed to be a function of growth in a preceding year, regression analysis is appropriate. Furthermore, as pointed out by Scott (1949), regression analysis permits the expected decrease in growth in year y to be expressed in terms of each unit of growth achieved in year x. A negative regression coefficient indicates compensatory growth, and its value is a relative measure of the amount of growth compensation.

In the present study, four year classes of striped bass (1953–1956) in Albemarle Sound, North Carolina, were sampled at the end of successive growing seasons. Increments of scale growth were regressed on increments of scale growth in the preceding year or years; the calculated regression coefficients were compared and used as relative measures of growth compensation.

Methods

Samples of striped bass were taken from commercial catches during the winter fishing season, October to March, 1955–1958, as part of tagging and catch sampling studies. Fork length of each fish was measured to the nearest 0.1 inch, method of capture was recorded, and scales for age determination were taken from the left side above the lateral line between the two dorsal fins.

Impressions of scales were made in cellulose acetate and examined on an Eberbach scale projector at a magnification of 40.5 diameters. The method of age determination of other investigators was followed (Merriman 1941; Mansueti 1961). Since growth was assumed to have ceased by the date of capture, an assumption supported by the work of Vladykov and Wallace (1952) and by personal observations of scales and length data from Albemarle Sound striped bass, the scale edge was considered as an annulus. A fish with one actual annulus, having completed two seasons of growth, would be placed in age group II. For example, a 1954 year class fish would be classified as age II during the October 1955 to March 1956 sampling period.

Samples of the 1953 year class were obtained at ages III, IV, and V, the 1954 year class at ages II, III, and IV, the 1955 year class at ages II and III, and the 1956 year class at age I.

Age groups II and III were obtained only from pound nets and haul seines, while age groups IV and V were obtained from gill nets as well. The gill nets were of a mesh size that took primarily fish of age groups II and III, and caught the older fish only incidentally. It was assumed that the gear was non-selective of fish size for each age group.

Merriman (1941) showed that the ratio of scale length to body length for striped bass was linear. In the present paper, therefore, annual increments of scale growth were used as a measure of annual body growth to eliminate calculating fish lengths from scale length measurements. Th anterior radius of the scale image wa measured in millimeters.

Increments of scale growth in one yea were regressed on increments of scal growth in a preceding year. An incremen was represented by x when used as the in dependent variable and by y when used a the dependent variable, with numeric subscripts to identify the year of growt For example, growth in year 3 was ident fied as x_3 when used as the independen variable and y_3 when used as the dependen variable. To determine if the slope of eac regression line differed significantly fro zero, linearity was assumed and a t-te was made on each regression coefficient.

The number of regressions calculat for each growth relationship for each yea class depended on the number of ag groups represented. If a year class wa represented by more than one age grou more than one regression coefficient coul be calculated for the same relation. Fo example, three regression coefficients $y_2 \cdot x_1$ were calculated for the 1953 yea class.

Results and Conclusions

Estimates of the regression coefficient $y_2 \cdot x_1$ were obtained for all age groups an year classes sampled. All were negativ and with one exception, significantly diffe ent from zero (Table 1), thus indicatin that compensatory growth occurred year 2 for each year class.

All regression coefficients of $y_3 \cdot x_1$ als were negative and significant, indicatin compensatory growth in year 3, while tho for $y_4 \cdot x_1$ and $y_5 \cdot x_1$ were negative but n significant. The regression coefficients $y_3 \cdot x_1$, computed from age group III, we smaller than the coefficients of $y_2 \cdot x_1$, com puted from age group II, for all year classe indicating that the amount of compensato growth was less in year 3 than in year 2.

For each year class the difference $y_2 \cdot x_1$ regression coefficients was tested f significance by analysis of covarian (Table 2), assuming that the regressio were linear, the y_2 values were random distributed for each x_1 value, and there w

BLE 1. Regression coefficients, where scale growth in year 1 was the independent variable (x_1) and scale growth in subsequent years was he dependent variable (y_n) for striped bass, *Roccus saxatilis*, from Albemarle Sound, North Carolina.

lass	Regression Coefficients				Number of fish	Age Group
	$y_2 \cdot x_1$	$y_3 \cdot x_1$	$y_4 \cdot x_1$	$y_5 \cdot x_1$		
53	−0.037	-0.357^1	−0.139	−0.046	77	V
	-0.152^1	-0.214^1	−0.023		112	IV
	-0.336^1	-0.289^1			159	III
54	-0.172^1	-0.281^1	−0.027		279	IV
	-0.447^1	-0.388^1			160	III
	-0.520^1				399	II
55	-0.483^1	-0.122^1			123	III
	-0.378^1				426	II
56	-0.307^1				776	II

[1] $P < 0.05$.

equal variance of $y_2 \cdot x_1$ for all age groups in each year class.

For the 1953 year class, there was a significant difference between the regression coefficients for age groups III and V, but not for age groups III and IV, or IV and V.

For the 1954 year class, the difference between the regression coefficients was not significant for age groups II and III, but was significant for age groups III and IV, and II and IV. The difference between the coefficients of II and IV was not actually tested by covariance analysis, since the coefficient of age group II was greater than the one for age group III, and the sample number was larger.

For the 1955 year class, the difference between the regression coefficients was not significant for age groups II and III.

Also from Table 1 it may be seen that, for both the 1953 and 1954 year classes,

ABLE 2. Analysis of covariance of the regressions of year 2 on year 1 growth $(y_2 \cdot x_1)$ for the 1953, 1954, and 1955 year classes of striped bass, *Roccus saxatilis*, from Albemarle Sound, North Carolina.

Source of variation	Degrees of freedom	Reduced sum of squares	Mean squares	Variance ratios
53 year class				
Samples of age group III and age group V				
Deviations from average regression within ages	233	64,106		$\frac{1,236}{275} = 4.49^1$
Deviations from individual regressions	232	63,870	275	
Difference for homogeneity of regression	1	1,236		
Samples of age group III and age group IV				
Deviations from average regressions within ages	268	62,594		$\frac{724}{232} = 3.12$
Deviations from individual regressions	267	61,870	232	
Difference for homogeneity of regression	1	724		
Samples of age group IV and age group V				
Deviations from average regressions within ages	186	45,516		$\frac{206}{245} = 0.840$
Deviations from individual regressions	185	45,310	245	
Difference for homogeneity of regression	1	206		
54 year class				
Samples from age group III and age group IV				
Deviations from average regressions within ages	436	109,886		$\frac{10,624}{228} = 44.66^1$
Deviations from individual regressions	435	99,262	228	
Difference for homogeneity of regression	1	10,624		
Samples from age group II and age group III				
Deviations from average regressions within ages	556	136,920		$\frac{17}{247} = 0.069$
Deviations from individual regressions	555	136,903	247	
Difference for homogeneity of regression	1	17		
55 year class				
Samples from age group II and age group III				
Deviations from average regressions within ages	546	95,638		$\frac{231}{175} = 1.32$
Deviations from individual regressions	545	95,407	175	
Difference for homogeneity of regression	1	231		

[1] $P < 0.05$.

the regression coefficient of $y_2 \cdot x_1$ decreased (approached zero) as the age at which the samples were taken increased. Since some of the regression coefficeints were significantly different from each other, the increases must have been real and not due merely to sampling error. Scott (1949) also noted such a decrease in his study of rock bass, but did not attribute any special significance to it, assuming that the differences were due to sampling error.

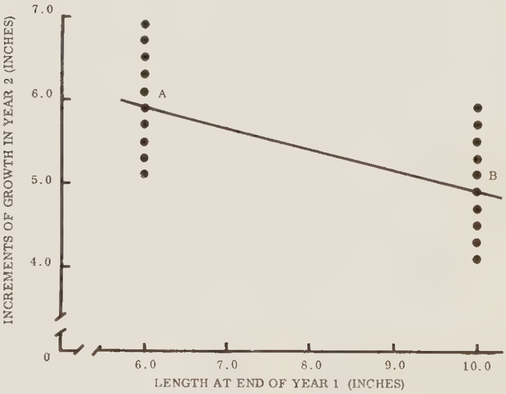

Fig. 1. Example from a hypothetical population showing growth in year 2, plotted on growth in year 1 to demonstrate compensatory growth.

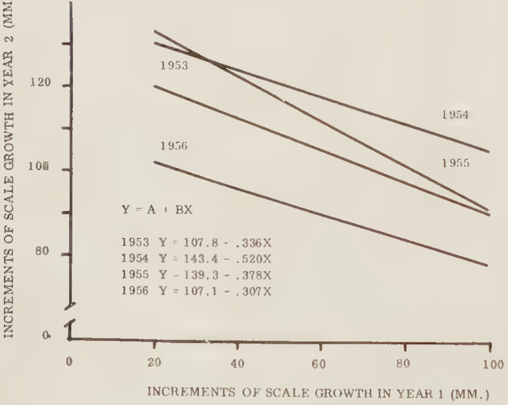

Fig. 2. Growth relation between years 1 and 2 for 1953–1956 year classes of striped bass, *Roccus saxatilis*, from Albemarle Sound, North Carolina. (Growth measured at 40.5 diameters magnification.)

TABLE 3. Mean increments of scale growth in millimeters for the 1953–1956 year classes of striped bass, *Roccus saxatilis*, from Albemarle Sound North Carolina (Growth measured at 40. diameter magnification).

Year Class	Mean increment of scale growth for years					Number of fish	Age Group
	1953	1954	1955	1956	1957		
1953	44.06	93.32	65.92	51.31	20.68	77	V
	47.65	97.86	64.38	53.46		112	IV
	52.04	107.75	69.40			159	III
1954		44.84	109.22	73.06	32.71	279	IV
		43.85	105.31	68.37		160	III
		53.30	115.95			399	II
1955			43.04	123.50	52.94	123	III
			43.48	122.82		426	II
1956				65.64	86.99	776	II

TABLE 4. Regression coefficients, where scale growth in years 2, 3, and 4 were the independent variables ($x_2 \cdot x_3 \cdot x_4$) and scale growth in each subsequent year was the dependent variable (y_n), for striped bass, *Roccus saxatilis*, from Albemarle Sound, North Carolina.

Year Class	Regression Coefficients						Number of fish	Age Group
	$y_3 \cdot x_2$	$y_4 \cdot x_2$	$y_5 \cdot x_2$	$y_4 \cdot x_3$	$y_5 \cdot x_3$	$y_5 \cdot x_4$		
1953	−0.152[1]	−0.088	−0.015	0.254[1]	0.094	0.082	77	
	−0.034	−0.015		−0.174[1]			112	I
	−0.185[1]						159	II
1954	−0.263[1]	−0.211[1]		−0.311[1]			279	I
	−0.341[1]						160	II
1955	−0.007						426	II

[1] $P < 0.05$.

An understanding of how the slope of the regression line of $y_2 \cdot x_1$ could have decreased in samples from successive years can best be illustrated by a hypothetical example. In this example, increments of growth in year 2 are plotted on increments of growth (lengths) in year 1 (Fig. 1). Ten fish arbitrarily are used in each size class of the x variable, but for simplicity those from size classes 6.1 to 9.9 are not plotted Assume the sample was taken at the end of year 2. In order for the slope of the regression line to be less (approach zero) in samples taken at the end of year 3 or year 4 (assuming no sampling error), the following events must occur: (1) in the 6. size class a disproportionate number of fish must be removed from above point A, thus decreasing the mean and the degree of slope of line AB, (2) in the 10.0 size class a disproportionate number of fish must be moved from below point B, thus increas- g the mean and decreasing the degree of ppe of line AB. If either one or both ents occur, the slope of line AB will crease.

No good explanation can be offered to plain why or how this mechanism oper- ed to cause a progressive increase in the gression coefficients of $y_2 \cdot x_1$ (and a pro- essive decrease in slope) in the 1953 and 954 year classes of striped bass in Albe- arle Sound. There is some similarity be- ween the progressive increase in the re- ession coefficients shown here and Lee's henomenon, the underestimation of aver- ge length when back-calculated from older sh. It is an interesting point that could e explored in other populations of fish here random samples of a single year ass are available at successive ages.

To determine if there was any difference the amounts of growth compensation in ear 2 among the four year classes, the egression coefficients of $y_2 \cdot x_1$ were tested or homogeneity by analysis of covariance, nd the regression lines were plotted (Fig.). Since for some year classes the coeffi- ients increased as the population grew lder, the age group II samples were used or all except the 1953 year class. For this ear class the age group III sample was used ecause no age group II sample was avail- ble.

The differences between the regression oefficients were not significant, indicating hat there was no difference in the relative mounts of compensatory growth among he four year classes. The differences in the alculated intercept on the y-axis were gnificant, but this would be expected, nce the amounts of growth varied con- derably each year (Table 3).

In comparison with growth in either years 2, 3, or 4, compensatory growth in succeeding years was more difficult to demonstrate (Table 4). In terms of year 2, compensatory growth was apparent in year 3 ($y_3 \cdot x_2$) for the 1953 and 1954 year classes, but not for the 1955 year class, and in year 4 for the 1954 year class, but not in years 4 or 5 ($y_4 \cdot x_2$; $y_5 \cdot x_2$) for the 1953 year class. In terms of year 3, compensatory growth appeared to occur in year 4 for the 1954 year class, but not in years 4 or 5 ($y_4 \cdot x_3$; $y_5 \cdot x_3$) for the 1953 year class. In terms of year 4, no compensatory growth was apparent in year 5 ($y_5 \cdot x_4$) for the 1953 year class.

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nvironmental requirement f the crested goby in ood Canal, Washington

Some environmental relationships the philobenthic crested goby *(Core- iopterus nicholsii)* were noted on ree dives made during the summer 1963 on the west shore of Hood anal. Two SCUBA dives were made Point Whitney on July 8 and Sept. ', and a snorkel dive was made 24 rect miles to the south near the town Hoodsport on Aug. 14. The dives ere made off similar gravel beaches here the rocks had been washed ean by the surf action above the in- nence of the tide. Beyond this the cks were covered by a heavy de- osit of fine gray sediment. The beach d a moderate slope to a depth of out ten feet below the mean low w water tide and then broke into e steep sides of the Hood Canal ench. A dense floral band of *Zostera* termixed with *Cystophyllum* was esent between the approximate pths of 2 and 12 feet below the ean low low water tide level. The rface water temperature on Septem- er 17 was 62°F. A thermocline was tected at about 35 feet, but the ex- t depth and temperature change ere not observed.

Cursory observations made on the st dive were sufficient to identify the ecies of the goby, indicate the main undances at depths of 15 to 35 feet d to reveal the fish's activity pat- rn. The crested gobies were not en to bury themselves in the soft ottom or to take advantage of bottom ojects for cover. Contrarily, they ere repeatedly moving about on the en bottom, making short darts and en remaining motionless for a few conds. Harassment by the diver did ot alter this behavior except for in- iating a dart.

The second dive revealed a string- nt relationship between the crested gobies and the sediment covered bottom. They were never seen on the clearly demarked surf-washed gravel, although they commonly moved to within six inches of it. The crested gobies were most abundant in the area of the *Zostera,* and relatively few individuals were seen from this area shoreward to the end of the sedimentation.

Some estimates of the population density of the crested gobies with depth were made a month later on the third dive. They abruptly increased in numbers with depth at a point slightly shoreward from the *Zostera* band. From the *Zostera* band to a depth of 35 feet (25 feet below the zero level) there was about one goby to the square foot. This population was dominated by the young of the year which had not been noted on previous dives that summer. Beyond 35 feet, the thermocline was felt, no young of the year were observed and goby abundances decreased to about one per ten square feet at a depth of 60 feet.

The ecological requirement which most profoundly determines the distribution of the crested goby is probably the bottom type. The observations made in Hood Canal and other Puget Sound areas indicate the crested goby receives a strong positive stimulus from the fine sediment bottom. This stimulus is likely tactile or visual, or a combination of these. The apparent widespread abundances of the crested goby along the west shore of Hood Canal are probably a result of an ideal habitat provided by gentle tides and surf allowing a sediment buildup on the steep slope.

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PINK SALMON SCALE STUDIES

by Roger E. Pearson

Six meristic characters were used to classify pink salmon taken from the Bering Sea and North Pacific Ocean in 1959 to continent of origin (Pearson, 1961). The spawning regions of eastern Kamchatka and western Alaska were assumed to be the destinations of pink salmon taken on the high seas. Consequently, meristic characters taken from eastern Kamchatkan and western Alaskan fish were used to compute continental morphotypes. The resulting classification

International North Pacific Fisheries Commission, Annual Report 1963,
Vancouver, Canada, p. 162-165, 1964.

criteria correctly assigned 85.7 per cent of the individual fish in the eastern Kamchatkan and western Alaskan samples to their continent of origin. Subsequent research was directed toward the following objectives: (1) to determine whether the classification criteria computed from the 1959 data would satisfactorily classify pink salmon collected in other years, (2) to determine whether scale characters alone could be used to classify fish taken on the high seas into spawning region groups with a high probability of correct classification, and (3) to determine methods of increasing the size of scale samples.

Classification of 1957, 1958 and 1960 Inshore Samples Using Criteria Based upon the 1959 Data

Pink salmon collected from Asian and North American inshore areas in 1957, 1958 and 1960 were examined with the classification criteria based upon the 1959 data. The results showed that the criteria that successfully classified Asian and North American pink salmon caught in 1959 could not be used to classify fish caught in 1957, 1958 and 1960. Although the discriminant function computed from the 1959 data was not suitable for pink salmon collected in other years, it is possible that some other function (linear combinations) of the same six characters would produce a satisfactory classification criteria for salmon collected in any one year.

The Use of Scale Characters Alone to Classify Pink Salmon Taken on the High Seas

Two groups of meristic characters have been examined for differences between populations of pink salmon. The first group was scale characters. Here, a scale was obtained from the body of the fish and later examined. The second group was obtained from radiographs of ossified structures. Here, whole fish specimens were collected at the sampling site and later processed in the laboratory. Both groups of characters were found to frequently vary between populations of fish. However, scale samples were more convenient to obtain and less costly to process than samples of whole fish. Therefore, the use of scale characters alone to classify pink salmon taken on the high seas was studied.

Classification criteria for the 1959 data using four scale characters and two characters from radiographs assigned 85.7 per cent of the individual pink salmon in the eastern Kamchatkan and western Alaskan samples to their continental type. When the four scale characters were used alone, the classification criteria correctly assigned 79.9 per cent of the individual pink salmon to their continental type. These results indicated that further research on scale characters alone might lead to classification of fish taken on the high seas with a high probability of correct classification.

Methods of Increasing the Size of Pink Salmon Scale Samples

Scale characters were obtained from only 50 per cent of the whole fish specimens collected in 1959. This was caused by (1) poor plastic scale impressions, (2) the collection of absorbed or regenerated scales, and (3) the absence of scales from the preferred body position on the fish. Since these factors greatly reduced sample size, they were examined to determine methods of minimizing scale losses.

The poor plastic scale impressions have largely been eliminated by means of an improved gummed paper for holding the scales (Clausing, 1963). Similarly, the number of absorbed or regenerated scales selected can be lessened by examining each scale with a high quality 6 to 10 power magnifier before the scale is placed on gummed paper.

The losses due to missing scales on whole fish (formerly processed in the Seattle Biological Laboratory) have been substantially reduced by taking the preferred scale on the sampling site at the earliest opportunity. This preferred scale was found two rows above the lateral line on the diagonal scale column which extends downward from the posterior insertion of the dorsal fin on either the left or right side of the fish. Since these scales are frequently missing or regenerated, an effort was made to enlarge the body area from which the preferred scale could be selected.

Scales were taken from body zones designated "A" and "B" by the International North Pacific Fisheries Commission (Proceedings of the 1957 Annual Meeting, 1958) on both the left and right sides of a pink salmon caught in Karluk Lagoon on July 28, 1960. The zones were subdivided into sub-zones of four vertical scale rows and 15 horizontal scale rows. Sample sizes ranged from 14 to 20 scales per sub-zone. Arithmetic mean values for 12 of the 27 scale characters examined were larger in the sampled posterior body zones (Table 28). These means followed a pattern similar to the number of circuli from the focus to the annulus as shown in Figure 33. Arithmetic mean values of the remaining 15 characters (Table 29) were larger in the sampled anterior body zones; they followed a pattern similar to the length from the center of the focus to the thirtieth circulus as shown in Figure 34. One-way analysis of variance tests indicated that the part of the "A" zone above the lateral line on the

TABLE 28. Pink salmon scale circuli counts examined for use as meristic characters.

1. The number of circuli from the focus to the annulus.
2. The number of circuli in the first half of the distance from the focus to the annulus.
3. The number of circuli in the second half of the distance from the focus to the annulus.
4. The number of circuli in the first third of the distance from the focus to the annulus.
5. The number of circuli in the second third of the distance from the focus to the annulus.
6. The number of circuli in the third third of the distance from the focus to the annulus.
7. The number of circuli in the first sixth of the distance from the focus to the annulus.
8. The number of circuli in the second sixth of the distance from the focus to the annulus.
9. The number of circuli in the third sixth of the distance from the focus to the annulus.
10. The number of circuli in the fourth sixth of the distance from the focus to the annulus.
11. The number of circuli in the fifth sixth of the distance from the focus to the annulus.
12. The number of circuli in the sixth sixth of the distance from the focus to the annulus.

TABLE 29. Pink salmon scale circuli measurements examined for use as meristic characters. All scales were examined at X100 magnification. Each measurement was to the nearest millimeter.

1. The width of the narrowest band of three successive circuli interspaces included between circuli 1 to 10.
2. The length from the center of the focus to the fifth circulus.
3. The length from the center of the focus to the tenth circulus.
4. The length from the center of the focus to the fifteenth circulus.
5. The length from the center of the focus to the twentieth circulus.
6. The length from the center of the focus to the twenty-fifth circulus.
7. The length from the center of the focus to the thirtieth circulus.
8. The length from the fifth to the tenth circulus.
9. The length from the tenth to the fifteenth circulus.
10. The length from the fifteenth to the twentieth circulus.
11. The length from the twentieth to the twenty-fifth circulus.
12. The length from the twenty-fifth to the thirtieth circulus.
13. The length from the fifteenth to the thirtieth circulus.
14. The length from the tenth to the twentieth circulus.
15. The length from the twentieth to the thirtieth circulus.

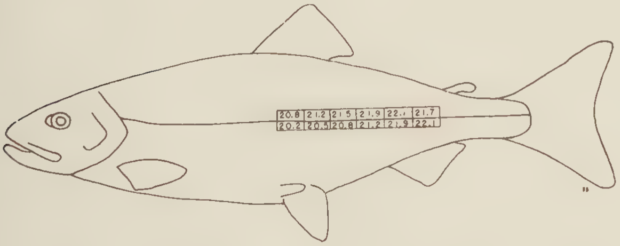

FIGURE 33. Arithmetic mean values of the number of circuli from the focus to the annulus on "A" and "B" zone scales (pooled variance within sub-zones equals 0.99).

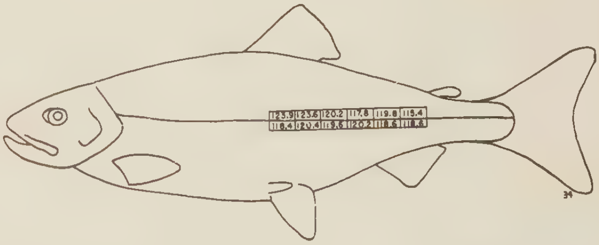

FIGURE 34. Arithmetic mean values of the length from the center of the focus to the thirtieth circulus on "A" and "B" zone scales (pooled variance within sub-zones equals 37.35).

left and right side of the fish could be used. In the future, scales will be taken from this area when the preferred scale is missing.

A great many high seas scale samples have been taken from a body position above the "A" zone. If these scales were similar to "A" zone scales, a greater number of samples would be available for our studies. Therefore, scales from the body area sampled on high seas fish were examined to determine if their mean values were similar to those from that part of the "A" zone above the lateral line.

The results of this study indicated that the arithmetic mean values were higher in the "A" zone for all scale characters examined. Scale characters in Table 28 follow a pattern similar to the number of circuli from the focus to the annulus (Figure 35).

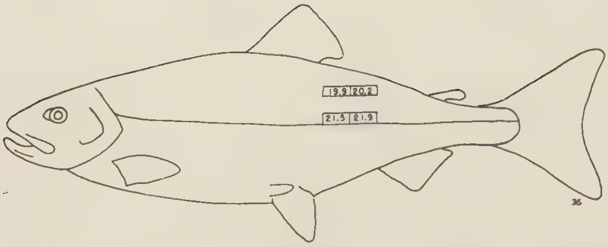

Figure 35. Arithmetic mean values of the number of circuli from the focus to the annulus on "A" zone scales from above the lateral line and scales from the body area sampled on high seas fish.

Scale characters in Table 29 follow a pattern similar to the length from the center of the focus to the thirtieth circulus (Figure 36).

These analyses show that a greater degree of uniformity in pink salmon scale sampling procedures among agencies of the International North Pacific Fisheries Commission will be necessary for our future studies.

Summary and Conclusions

Pink salmon collected in 1957, 1958 and 1960 were examined with the classification criteria based upon the 1959 data. The results of this study indicated that the discriminant function computed from the 1959 data was not suitable for the salmon collected in other years.

The use of scale characters alone to classify pink salmon taken on the high seas was studied. The scale characters were found to correctly assign 79.9 per cent of the individual fish in the 1959 eastern Kamchatkan and western Alaskan samples to their continental type. The addition of two characters obtained from radiographs of ossified structures raised the value to 85.7 per cent. The results of this study indicated that scale characters alone might classify fish taken on the high seas with a high probability of correct classification.

Several methods of increasing the size of pink salmon scale samples were examined. As a result of these studies, the number of poor plastic scale impressions, regenerated scales and absorbed scales was lessened. Selection of scale samples from that part of the "A" zone above the lateral line has increased the utility of the samples, but still greater uniformity in sampling procedures is needed. Precise results from future research will depend on the selection of scales from a specific body area.

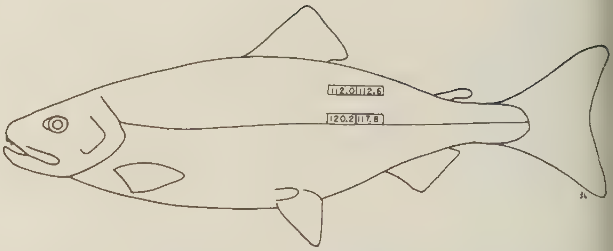

Figure 36. Arithmetic mean vaues of the length from the center of the focus to the thirtieth circulus on "A" zone scales from above the lateral line and scales from the body area sampled on high seas fish.

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USE OF A DISCRIMINANT FUNCTION TO CLASSIFY NORTH AMERICAN AND ASIAN PINK SALMON, *ONCORHYNCHUS GORBUSCHA* (WALBAUM), COLLECTED IN 1959

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ABSTRACT

A discriminant function analysis with six morphological characters was used to determine the continental origin of pink salmon (*Oncorhynchus gorbuscha*) taken from the Bering Sea and North Pacific Ocean in 1959. The spawning regions of eastern Kamchatka and western Alaska were assumed to be the destination of the pink salmon taken on the high seas. Consequently, morphological characters taken from eastern Kamchatkan and western Alaskan fish were used to compute continental morphotypes. Applying the function, pink salmon populations from all North American inshore areas were well separated from the eastern Kamchatkan morphotype. Alaskan morphotype fish were dominant in the two high seas samples taken at longitude 160°W. in the North Pacific Ocean, in one sample taken at longitude 177°W. in the North Pacific Ocean, and in one sample taken at longitude 170°W. in the Bering Sea. Eastern Kamchatkan morphotype fish were dominant in all other high seas samples taken at longitude 170°W. and to the westward. No high seas samples were taken between longitudes 170°W. and 160°W.

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INTRODUCTION

The Bureau of Commercial Fisheries, United States Fish and Wildlife Service, is engaged in several investigations for the International North Pacific Fisheries Commission (INPFC). This commission was established to promote and coordinate scientific studies pertaining to conservation measures required to secure the maximum sustained productivity of fisheries in the North Pacific Ocean and Bering Sea. One species of joint interest to the member nations is the pink salmon, *Oncorhynchus gorbuscha* (Walbaum).

Pink salmon spawn in the coastal streams of Asia and North America, but spend most of their two-year life span in the high seas areas of the North Pacific Ocean and Bering Sea. The Commission is attempting to determine whether there are high seas areas in which pink salmon originating in the rivers of Canada and the United States intermingle with pink salmon originating in the rivers of Asia. When such areas are found, the Commission is instructed to determine a line or lines which best divide salmon of Asiatic origin from salmon of North American origin. To accomplish this objective, it is necessary to distinguish Asian from North American pink salmon in high seas samples.

This paper describes a method of determining the origin of pink salmon caught on the high seas in 1959. Here, six morphological characters were selected to separate samples of known origin into a continental group (morphotype) with a low probability of misclassification. The same characters were then used to classify salmon taken on the high seas into a continental morphotype with a known probability of misclassification.

The objectives of this study were: (1) to select morphological characters capable of distinguishing Asian from North American pink salmon; (2) to define continental morphotypes based on these characters; and (3) to estimate the contribution of each morphotype to high seas samples.

Many members of the staff of the Bureau of Commercial Fisheries Biological Laboratory at Seattle, Washington, aided in various ways. I wish to express my appreciation to them. They were Raymond Anas, Douglas Clausing, Donald Worlund, Sueto Murai, Ernest Decorvet, George Slusser, Leona Allison, Clifford Burner, Fred Cleaver and Paul Macy.

EXPERIMENTAL PROCEDURE

Methods of Sampling

Samples of whole pink salmon were collected from inshore fisheries in North America and from high seas areas of the North Pacific Ocean and Bering Sea. Appendix A lists the location, date and number of fish collected in 1959.

The North American inshore samples were obtained by means of gillnets, beach seines and purse seines. These fish were collected from streams or rivers where pink salmon were known to spawn. An attempt was made to obtain all samples at the peak of the run from streams which were major contributors to the local fisheries. The principal commercial fisheries of North America were represented, but the remote areas of the Aleutian Islands and northwestern Alaska where a personal use fishery exists (INPFC, 1962) were not adequately sampled.

High seas samples were obtained from the Japanese commercial fishery and from Japanese, Canadian and United States research vessels. The Japanese commercial fishery samples were obtained from both the mothership fleet off the east coast of the Kamchatka Peninsula and from Hokkaido Island landbased vessels. These samples were caught in gillnets with 4.8″ stretched measure between opposite knots. The Japanese research vessels fished with longline gear. The United States and Canadian research vessels used a standard string of gillnets with mesh sizes of $2\frac{1}{2}$″, $3\frac{1}{4}$″, $4\frac{1}{2}$″ and $5\frac{1}{4}$″ stretched measure between opposite knots.

All specimens were preserved by freezing and later transported to the Seattle Biological Laboratory of the Bureau of Commercial Fisheries at Seattle, Washington, for examination.

Methods of Data Collection

Six morphological characters were used to classify the 1959 collections to continent of origin. Four were taken from scales and two from radiographs of ossified structures.

The scale characters were: (1) the number of circuli in the first half of the distance from the outermost edge of the center ring to the annulus; (2) the number of circuli in the second half of the distance from the outermost edge of the center ring to the annulus; (3) the number of circuli in the second sixth of the distance from the outermost edge of the center ring to the annulus; (4) the width in millimeters of the narrowest band of three successive circuli interspaces included between circuli 1 to 10 (either circuli 1 to 4, 4 to 7, or 7 to 10). The scales were taken from the fish, cleaned in a detergent solution, and mounted with the sculptured side up on gummed paper. Scales were taken from the body position two rows above the lateral line on the diagonal scale column which extends downward from the posterior insertion of the dorsal fin. Plastic impressions (Clutter and Whitesel, 1956) of the mounted scales were made on clear cellulose acetate cards. A projection microscope (Mosher, 1950) was used to examine the plastic scale impressions at 100 × magnification. All scales collected in 1959 were examined by one worker. This worker could accurately repeat circuli counts and measurements (Appendix B).

The characters obtained from radiographs were: (1) the number of branchiostegal rays on the left side of the head and (2) the number of vertebrae beginning with the atlas and terminating with the urostyle. Permanent photographic records of these characters were obtained by use of X-ray technique. The structures on every radiograph were counted by a trained worker and verified by another. Doubts as to the number of branchiostegal rays were resolved by staining (Hollister, 1934) and counting the rays on the stained branchiostegal.

It was not always possible to collect every character from each specimen (Appendix C). This was particularly true in regard to scales. Fifty percent of the specimens came into the laboratory with missing or absorbed scales from the preferred body position.

The body length from the end of the hypural plate to the middle of the eye was measured on each fish. This measurement was considered to be the least affected by sexual maturity or by possible body damage incurred while handling and transporting the frozen specimens. The measurement was not used as a character to classify the 1959 collections. It was used to determine if the characters were related to fish length.

Each character was examined for sexual differences and the effect of fish length (Appendix D). The results of the examinations indicated that these two possible sources of variation would not bias the classification of samples taken from the high seas.

METHOD OF ANALYSIS

A discriminant function analysis was selected to classify the 1959 high seas collections to continent of origin. The discriminant function analysis (Fisher, 1936) is a multivariate normal technique by which individual fish may be classified to one of two groups by means of a set of morphological characters. The six previously mentioned characters were used (1) to define a representative continental morphotype composed of samples of known origin and (2) to separate the high seas collections into North American and Asian morphotypes. It is necessary to assume that the high seas collections originated from areas represented by the samples composing the morphotypes. The presence of fish from other areas would affect the calculated probability of correctly classifying individual fish into either morphotype.

The statistical assumptions for obtaining the best discriminant function analysis require the characters to have multivariate normal distributions with a common dispersion matrix in the populations selected for use as continental morphotypes. Common variance and common correlation are conditions that indicate a common dispersion matrix. Linear relationship between all possible pairs of characters and normality of each character are important conditions in multivariate normal distributions.

In a previous study, a discriminant function analysis was used to classify pink salmon collected on the high seas in 1957 to continent of origin (Amos, Anas and Pearson, 1963). It was found that additional characters were needed to separate pink salmon of the Alaska Peninsula, Aleutian Islands and northwestern Alaska from those of Kamchatka. For this reason, the characters used here are substantially different from those used by Amos, Anas and Pearson (1963).

RESULTS

SELECTION OF SAMPLES FOR MORPHOTYPES

The continental morphotypes were composed of samples from spawning regions that were the destination of the fish caught on the high seas. Two offshore samples from the east coast of the Kamchatka Peninsula were selected to represent the Asian spawning region and five inshore samples from central and western Alaska were selected to represent the North American spawning region.

The selection of eastern Kamchatka as the destination of the Asian fish and western Alaska as the destination of the North American fish was based on (1) the results of tagging experiments, (2) sizes of coastal catches and (3) proximity of the spawning regions to the offshore sampling areas (Fig. 1).

High seas tagging by United States research vessels in 1959 resulted in 129 recoveries from the high seas and 39 from the east coast of the Kamchatka Peninsula (INPFC, 1960). A dominant northwest movement of tagged fish toward the Karaginski region in eastern Kamchatka is observed from the tag returns (Fig. 2). Although tagged fish were not recovered from North American inshore areas in 1959, pink salmon tagged in the Aleutian areas were recovered in North America in 1958, 1960, 1961 and 1962 (Hartt, 1961; INPFC, 1961; Rausch and Hartt, 1962). Except for one recovery from the south side of the Alaska Peninsula, all North American tag recoveries were from western Alaska.

The pattern of recovery from Japanese high seas tagging in 1959 was similar to the United States recovery pattern (INPFC, 1961). The coastal recoveries from fish tagged in Aleutian and Bering Sea waters were all from eastern Kamchatka. However, coastal recoveries in the Okhotsk Sea area were reported from tagging in the western areas of the North Pacific Ocean. The easternmost tagging location yielding a return to an Okhotsk Sea spawning region was at 163° E. Tagging experiments by the Japanese have generally shown the high seas distribution of Asian pink salmon from the Okhotsk Sea coast, Sakhalin, Kuril, Primorski and Hokkaido Island areas to be southwest of Aleutian and Bering Sea waters (INPFC, 1961).

Eastern Kamchatka was the closest major Asian spawning area to the location of the high seas samples. It was found to have the largest Asian coastal catch in 1959 (Table 1). Since it was not possible to collect inshore samples from this region, it was

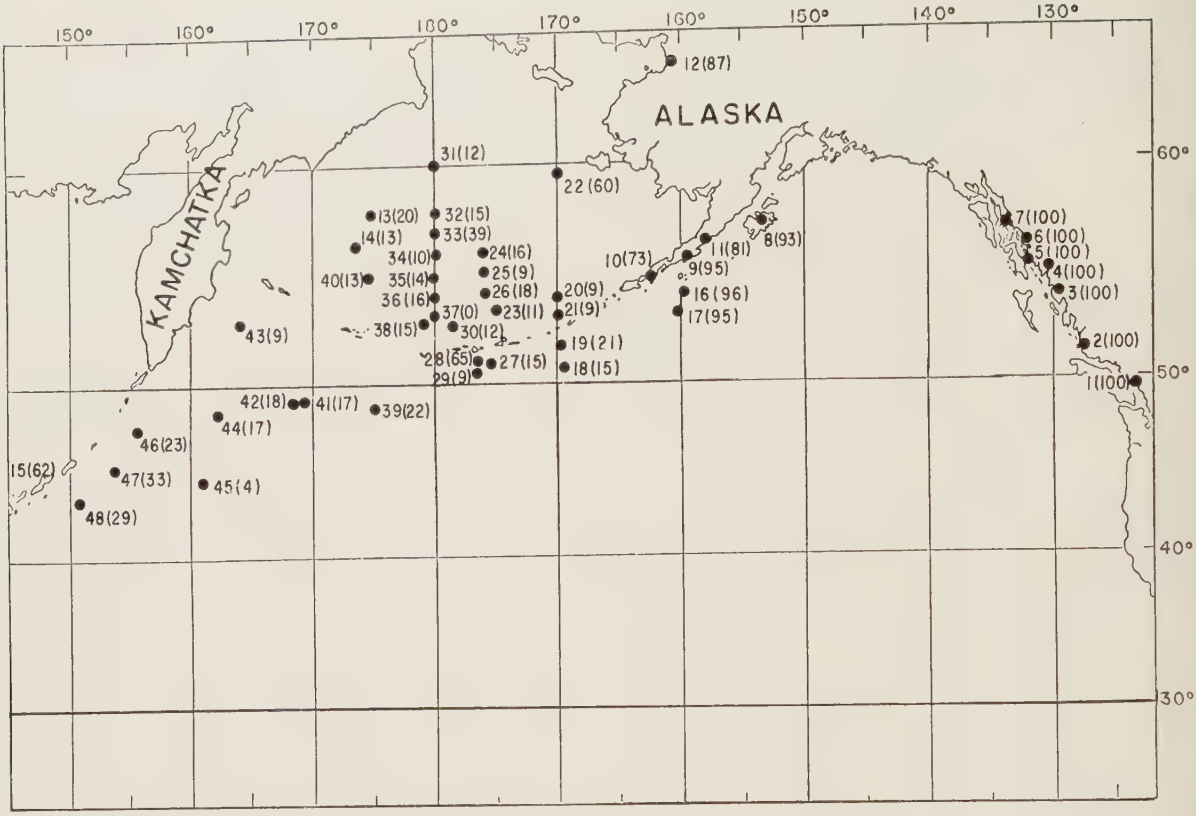

Figure 1. Sampling locations for 1959 pink salmon. The first number indicates sample map number (see Tables 6 and 7). The second number indicates percent western Alaska-type fish in sample (see Tables 6 and 7).

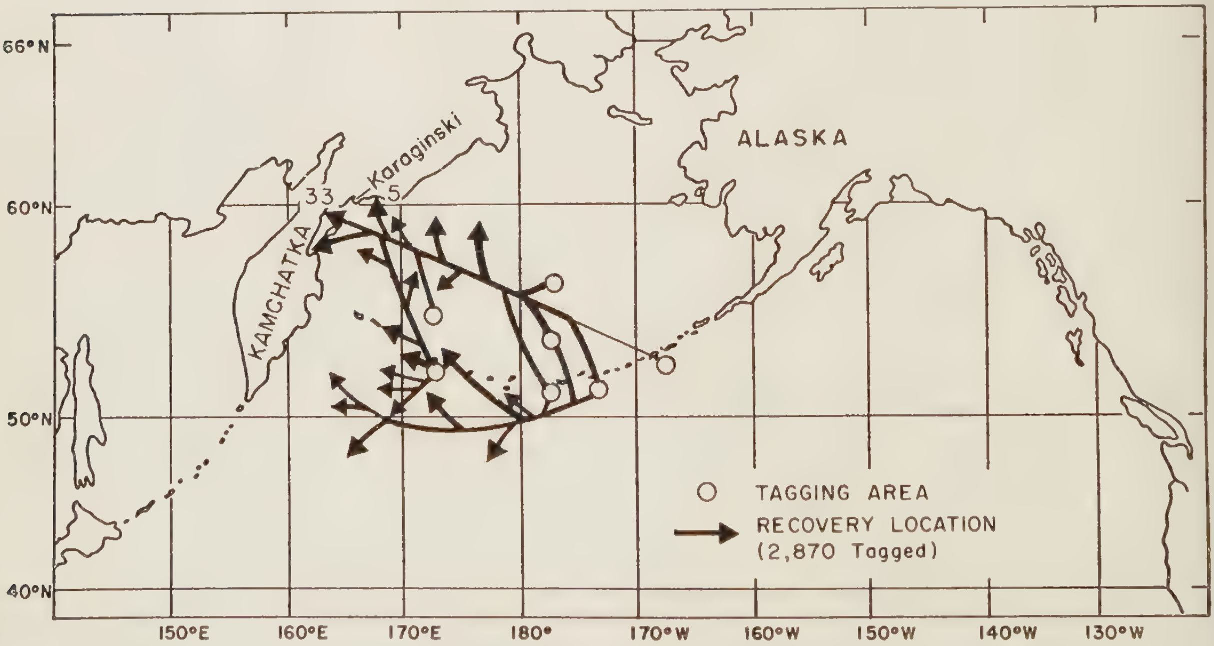

Figure 2. Recovery distribution of pink salmon tagged and recovered in 1959.

TABLE 1. Coastal catch of North American and Asian pink salmon in 1959.

Area	*Thousands of fish*
NORTH AMERICA[1]	
Western Alaska	22
Central Alaska	3,057
Southeastern Alaska	7,851
British Columbia	6,776
Washington	2,616
ASIA	
West Kamchatka[2]	6,806
East Kamchatka[2]	13,875
Sakhalin & Kuril Islands[2]	11,364
Okhotsk coast[2]	1,868
Amur[2]	612
Primorski[2]	1,722
Hokkaido Island[1,3]	58

[1] INPFC Statistical Yearbook 1959.

[2] Data submitted to the INPFC by VNIRO—INPFC Doc. 363 (converted from weight to number of fish with a rate of 1.3 kilograms per fish).

[3] Freshwater landings converted from weight to number of fish with a rate of 3.7 pounds per fish.

ecessary to use two high seas samples for the morphoype. These samples were taken at 58°00′N., 175° 00′E. on July 4 and 56°49′N., 173°22′E. on July 5. They were the largest samples taken close to the Karaginski region of eastern Kamchatka.

The most likely spawning destination of the North American pink salmon in the high seas samples was entral and western Alaska. Although fish tagged n Aleutian waters were not recovered from North American inshore areas in 1959, the results of tagging xperiments in other years showed that western Alaskan pink salmon were present westward to at east 177°E. and central Alaskan pink salmon were present westward to at least 168° W. (INPFC, 1961). Pink salmon tagged in Aleutian waters have not been recovered from North American spawning regions other than western and central Alaska.

Western and central Alaska were the closest North American spawning regions to the location of the high seas samples. Their combined 1959 catch was 3,079,000 fish. Although the combined central and western Alaskan catch is generally high in all years (INPFC, 1961), 1959 was a year of unusually low abundance.

Five inshore samples from central and western Alaska were selected for a morphotype. They were collected from Uyak Bay on Kodiak Island, Hook Bay on the Alaska Peninsula, Coal Bay Stream on the Alaska Peninsula, Ivanof Bay on the Alaska Peninsula and Unalakleet River on Norton Sound in northwestern Alaska.

The continental areas selected as the spawning destinations for the 1959 high seas samples may not be suitable for samples taken in other years. This is especially true for eastern Kamchatka where the coastal catch of pink salmon is generally high in odd-numbered years but low in even-numbered years (INPFC, 1961). In years of low abundance, such as 1956 when the coastal catch was 380,000 fish, we would not expect to find large numbers of eastern Kamchatkan pink salmon in Aleutian waters.

SELECTION OF CHARACTERS

The discriminant function analysis uses a set of multiple measurements to discriminate between any two groups (Fisher, 1936). It provides the best linear function for discriminating two morphotypes (Rao, 1952). Since this analysis was selected to classify the high seas samples to continent of origin, it necessitated the selection of characters that (1)

TABLE 2. Mean differences in morphological characters between the western Alaskan and eastern Kamchatkan morphotypes.

Morphological character	Morphotype	Character mean	Mean difference	Pooled variance
First half circuli	Western Alaska	11.5501		
	Eastern Kamchatka	10.3567	1.1934	0.6353
Second half circuli	Western Alaska	11.6314		
	Eastern Kamchatka	10.6722	0.9592	0.8548
Second sixth circuli	Western Alaska	3.8487		
	Eastern Kamchatka	3.3971	0.4516	0.2244
Narrowest three circuli	Western Alaska	10.7994		
	Eastern Kamchatka	12.0151	−1.2157	2.2167
Branchiostegal rays	Western Alaska	12.8381		
	Eastern Kamchatka	12.2155	0.6226	0.4388
Vertebrae	Western Alaska	68.6422		
	Eastern Kamchatka	69.3813	−0.7391	0.8019

TABLE 3. Results of tests for homogeneity of variance in morphological characters between morphotypes.

Character	Western Alaskan variance[1]	Eastern Kamchatkan variance[2]	Ratio	*F* value[3]
Number of circuli in first half	0.6219	0.6674	1.0732	1.34
Number of circuli in second half	0.8342	0.9042	1.0839	1.34
Number of circuli in second sixth	0.2192	0.2368	1.0803	1.34
Width of narrowest three circuli	2.0777	2.5510	1.2278	1.34
Number of branchiostegal rays	0.4411	0.4331	1.0185	1.37
Number of vertebrae	0.8107	0.7808	1.0383	1.37

[1] Sample size of 296 fish.

[2] Sample size of 123 fish.

[3] Significance level of five percent for a two-tailed test.

differed between morphotype means and (2) conformed to the statistical requirements of the function. Therefore, the six morphological characters were examined for differences between morphotype means and for conformity to the statistical requirements of a discriminant function.

The mean differences of the morphological characters were computed between the two morphotypes. The results of this study are found in Table 2. The first character, number of circuli in the first half, has a mean difference between morphotypes of 1.1934 circuli with a pooled variance of 0.6353. This character will correctly classify 77 percent of the fish. In a similar manner, the number of circuli in the second half will classify 70 percent of the fish; the number of circuli in the second sixth, 68 percent; the narrowest three circuli measurement, 66 percent; the number of branchiostegal rays, 68 percent; and the number of vertebrae, 66 percent. Each morphological character shows some degree of difference between morphotypes.

The statistical assumptions for obtaining the best discriminant function require the characters to have: (1) a common dispersion matrix in the populations selected for use as continental morphotypes and (2) multivariate normal distributions. The characters were examined for conformity to these requirements.

Common variance and common correlation are conditions that indicate a common dispersion matrix. Common variance was tested by a variance ratio test in which the larger variance was the numerator and the smaller variance the denominator. The values obtained were compared with the values in *F*-distribution tables with the appropriate degrees of freedom. The results of this test are shown in Table 3. None of the *F* values was significant at the five percent level.

Common correlation between all possible pairs of characters in each morphotype was examined with a test given by Snedecor (1956). Average sample correlation coefficients were calculated for each morphotype. The *r* values were converted by tables to Fisher's *z* values. The differences between the *z* values were divided by the standard error of the difference to obtain *t* values with infinite degrees of freedom. The results of these tests are found in Table 4. Of the 15 pairs examined, two significant differences were found between morphotypes. The character pairs were (1) first half circuli—second half circuli and (2) second half circuli—second sixth circuli. In the first pair, the morphotype with the largest average correlation coefficient was eastern Kamchatka. Since the average correlation coefficient was 0.4859, the percent variation in one character attributable to the variation in the other was (100) $(0.4859)^2$ or 23.6. In the second pair, the morphotype with the largest average correlation was once again eastern Kamchatka. The calculated percent variation in one character attributable to the variation in the other was 17.4. Because of the lack of common correlation in the two character pairs, the best discriminant function may not be obtained. However, due to the low level of correlation and the relatively large differences between morphotype character means, the affected characters were included in the analysis.

Linearity of regression between the 15 possible pairs of characters and the frequency distribution curves of the six characters were examined for each of the two morphotypes. Linearity of regression is one of the conditions required for multivariate normal distributions of morphological characters. A polynomial regression was calculated to examine linearity of regression. The results of this test indicated no great departure from linearity by any of the character pairs.

Table 4. Results of tests for common correlation with the western Alaskan and eastern Kamchatkan morphotype samples between all pairs of characters.

Character pairs	Average correlation coefficients		
	Western Alaska	Eastern Kamchatka	t values
irst half circuli econd half circuli	0.2906	0.4859	2.1386*
irst half circuli econd sixth circuli	0.5421	0.6410	1.4113
irst half circuli arrowest three circuli	−0.3654	−0.5000	1.5360
irst half circuli ranchiostegal rays	−0.0063	−0.0279	0.1996
irst half circuli ertebrae	0.1028	0.1969	0.8900
econd half circuli econd sixth circuli	0.1256	0.4168	2.9344*
econd half circuli arrowest three circuli	0.2055	0.0947	1.0490
econd half circuli ranchiostegal rays	0.0833	0.0616	0.2015
econd half circuli ertebrae	−0.0403	0.0721	1.0397
econd sixth circuli arrowest three circuli	−0.3363	−0.3121	0.2495
econd sixth circuli ranchiostegal rays	−0.0561	0.0410	0.8983
econd sixth circuli ertebrae	0.0440	0.1243	0.7486
arrowest three circuli ranchiostegal rays	−0.0014	0.0851	0.8013
arrowest three circuli ertebrae	−0.0532	−0.0892	0.3336
ranchiostegal rays ertebrae	−0.0934	0.0143	0.9982

* Significant at the five percent level.

There are no adequate tests for normality of small mples (Fisher, 1944; Cochran, 1947). Fisher states at drastic departures are required before statistical rocedures based on normality are disturbed. Frequency distribution curves are given in Figure 3 for e six characters of each morphotype. No radical epartures from normality are evident. On this basis, e normality of the data is assumed to be adequate r the discriminant function.

onstruction of a Western Alaskan and Eastern Kamchatkan Discriminant Function

A discriminant function for western Alaskan and stern Kamchatkan pink salmon of the form $=l_1X_1+l_2X_2+l_3X_3+l_4X_4+l_5X_5+l_6X_6$ was calculated ing data from the variance-covariance matrix of

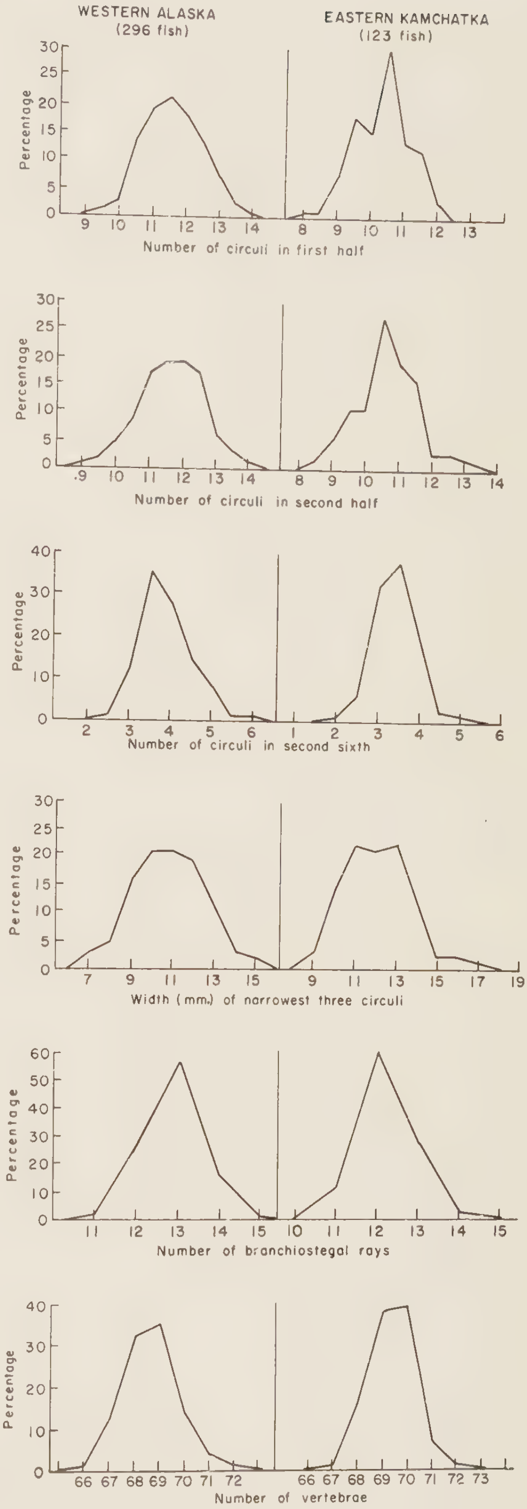

Figure 3. Frequency distributions of morphological characters used in separating western Alaskan and eastern Kamchatkan pink salmon morphotypes.

TABLE 5. The variance-covariance matrix and calculation of the discriminant function for the 1959 pink salmon collections[1].

Character		Variance-covariance matrix						Mean difference
		X_1	X_2	X_3	X_4	X_5	X_6	
First half circuli[2]	1.	63.5274	25.5602	21.7720	−4.7359	−0.0502	0.9108	11.9343
Second half circuli[2]	2.		85.4753	8.9694	2.3364	0.4838	−0.0887	9.5925
Second sixth circuli[2]	3.			22.4361	−2.3215	−0.1029	0.2878	4.5165
Narrowest three circuli	4.				2.2167	0.0257	−0.0731	−1.2157
Branchiostegal rays	5.					0.4388	−0.0398	0.6226
Vertebrae	6.						0.8019	−0.7391
	7.							0.0000
		Discriminant function matrices						
	11.	1.0000	0.4023	0.3427	−0.0745	−0.0008	0.0143	0.1879
	12.	0.4023	75.1924	0.2105	4.2417	0.5040	−0.4551	4.7913
	13.	0.3427		14.9748	−0.6985	−0.0857	−0.0243	0.4266
	14.	0.0745			1.8639	0.0220	−0.0052	−0.3266
	15.	−0.0008				0.4388	−0.0391	0.6321
	16.	0.0143					0.7904	−0.9098
	17.	0.1879						−2.2425
	22.	0.0054	1.0000	0.0028	0.0564	0.0067	−0.0061	0.0637
	23.	0.3416	0.0028	14.9742	−0.7104	−0.0871	−0.0230	0.4132
	24.	−0.0972	0.0564		1.6247	−0.0064	0.0205	−0.5968
	25.	−0.0035	0.0067			0.4354	0.0361	0.6000
	26.	0.0168	−0.0061				0.7876	−0.8806
	27.	0.1623	0.0637					−2.5477
	33.	0.0228	0.0002	1.0000	−0.0474	−0.0058	−0.0015	0.0276
	34.	−0.0810	0.0565	−0.0474	1.5910	0.0105	0.0194	−0.5772
	35.	−0.0015	0.0067	−0.0058		0.4349	−0.0362	0.6024
	36.	0.0173	−0.0061	−0.0015			0.7876	−0.8800
	37.	0.1529	0.0636	0.0276				−2.5591
	44.	−0.0509	0.0355	−0.0298	1.0000	−0.0066	0.0122	−0.3628
	45.	−0.0020	0.0071	−0.0061	−0.0066	0.4348	−0.0361	0.5986
	46.	0.0183	−0.0068	−0.0009	0.0122		0.7874	−0.8730
	47.	0.1235	0.0841	0.0104	−0.3628			−2.7685
	55.	−0.0046	0.0163	−0.0140	−0.0152	1.0000	−0.0830	1.3767
	56.	0.0181	−0.0062	−0.0014	0.0117	−0.0830	0.7844	−0.8233
	57.	0.1263	0.0743	0.0188	−0.3537	1.3767		−3.5926
	66.	0.0231	−0.0079	−0.0018	0.0149	−0.1058	1.0000	−1.0496
	67.	0.1453	0.0678	0.0173	−0.3414	1.2896	−1.0496	−4.4567

$$Y=0.1453X_1+0.0678X_2+0.0173X_3-0.3414X_4+1.2896X_5-1.0496X_6$$

Character	*Western Alaskan morphotype mean*	*Eastern Kamchatkan morphotype mean*
First half circuli $(X_1)^2$	115.5011	103.5668
Second half circuli $(X_2)^2$	116.3142	106.7217
Second sixth circuli $(X_3)^2$	38.4875	33.9710
Narrowest three circuli (X_4)	10.7994	12.0151
Branchiostegal rays (X_5)	12.8381	12.2155
Vertebrae (X_6)	68.6422	69.3813

Y Western Alaska $=-33.8435$

$Y_0=-36.0716$

Y Eastern Kamchatka $=-38.2998$

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[1] Using pivotal condensation method (Rao, 1952).

[2] Each character value was multiplied by 10 to facilitate use of automatic data processing equipment. The listed mean values are 10 times larger than they really are. The variances and covariances are 100 times larger.

TABLE 6. Classification of 1959 pink salmon morphotype and inshore samples to western Alaskan or eastern Kamchatkan morphotypes.

Map number[1]	Location	Date	Sample size	Percent classified	
				Western Alaskan	Eastern Kamchatkan
1	Fraser River (British Columbia)	9/1	45	100.0	0.0
2	Rivers Inlet (British Columbia)	8/14	52	100.0	0.0
3	Skeena River (British Columbia)	8/14	56	100.0	0.0
4	Ketchikan (southeastern Alaska)	8/16	26	100.0	0.0
5	Ketchikan (southeastern Alaska)	8/18	24	100.0	0.0
6	Petersburg (southeastern Alaska)	8/3	47	100.0	0.0
7	Petersburg (southeastern Alaska)	8/9	20	100.0	0.0
8	Uyak Bay (Kodiak Island)	8/6	60	93.3	6.7
9	Ivanof Bay (Alaska Peninsula)	7/30	63	95.2	4.8
10	Coal Bay (Alaska Peninsula)	8/1	66	72.7	27.3
11	Hook Bay (Alaska Peninsula)	8/13	47	80.9	19.1
12	Unalakleet (northwestern Alaska)	7/10	60	86.7	13.3
13	Eastern Kamchatka[2]	7/4	70	20.0	80.0
14	Eastern Kamchatka[3]	7/5	53	13.3	86.7
15	Yubetsu River (Hokkaido Island)	8/17	52	61.5	38.5

[1] Numbers refer to sampling locations in Figure 1.

[2] Sample was obtained offshore at 58°00′N., 175°00′E.

[3] Sample was obtained offshore at 56°49′N., 173°22′E.

Table 5. A description of this method of calculation is available from Rao (1952), who demonstrates that it produces the best linear discriminant function obtainable. The first six values in row 67, Table 5, are the coefficients (l's) needed for the equation. The equation then appears as $Y=0.1453X_1+0.0678X_2+0.0173X_3-0.3414X_4+1.2896X_5-1.0496X_6$, where X_1 is the number of circuli in the first half, X_2 is the number of circuli in the second half, X_3 is the number of circuli in the second sixth, X_4 is the width of the narrowest three circuli, X_5 is the number of branchiostegal rays and X_6 is the number of vertebrae. The last value in row 67 is the variance of Y or D^2 value.

The probability of correctly classifying an individual fish from one of the two morphotypes is equal to the probability that a normal deviate with mean zero and standard deviation of one will be less than, or equal to, $D/2$. Since D^2 has a value of 4.4567 (Table 5), $D/2$ equals 1.0555. The probability of correctly classifying a single fish into its morphotype is 85.7 percent.

CLASSIFICATION OF SAMPLES INTO MORPHOTYPES

Pink salmon samples with at least 20 usable fish were classified into either morphotype group with the calculated western Alaskan-eastern Kamchatkan discriminant function.

Table 6 gives the results of classifying the 1959 morphotype and inshore samples. Classification is presented as percentage of specimens in each sample resembling the western Alaskan morphotype (Y values greater than -36.0716) and eastern Kamchatkan morphotype (Y values less than -36.0716). The mean Y values were also placed on a straight line in order of magnitude (Fig. 4).

Twelve North American inshore samples were classified. Their mean Y values can be found in Figure 4. Since all values are greater than -36.0716, we would expect that individual fish will be classified predominantly into the western Alaskan morphotype. This is verified in Table 6 where the percentages range from 72.7 to 100. It is apparent that the morphological relationships of all North American inshore samples were such that the majority of their individual fish were classified into the western Alaskan morphotype. Therefore, we would expect high-seas-caught pink salmon originating from these areas to be predominantly classified as western Alaska-type fish.

The two samples used to represent eastern Kamchatka had mean Y values less than -36.0716. Individual fish from these samples were classified 80.0 and 86.7 percent into the Asian morphotype. Therefore, we would expect high-seas-caught pink salmon originating from this morphotype's spawning area to be predominantly classified as eastern Kamchatka-type fish.

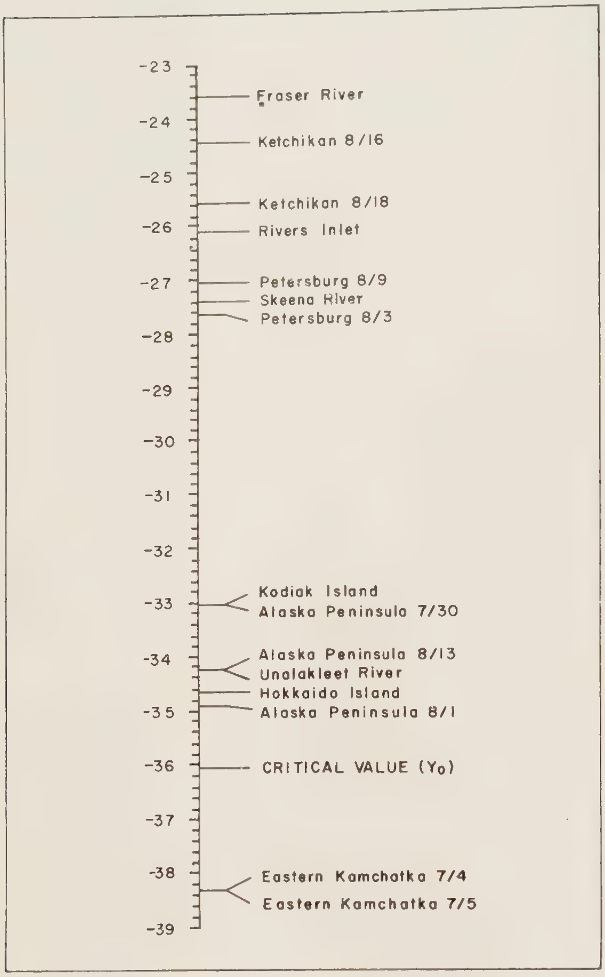

Figure 4. Linear comparison of mean discriminant scores of 1959 pink salmon morphotype and inshore samples.

An inshore sample collected from Hokkaido Island in Japan had a mean Y value greater than -36.0716. Over 61 percent of the fish in the sample were erroneously classified into the western Alaskan morphotype. However, the coastal catch of 58,000 fish (Table 1) from Hokkaido Island was small in comparison to 13,875,000 from eastern Kamchatka and 3,079,000 from central and western Alaska. Even if the fish from Hokkaido Island could be separated from the North American stocks, their presence would not greatly influence the high seas distribution pattern. Other Asian stocks from unsampled spawning regions may also have a high percentage of erroneously classified western Alaska-type fish. Some of these regions had large coastal catches in 1959 (Table 1). Intermingling of these fish with eastern Kamchatkan pink salmon might result in erroneously high estimates of the percentage of North American pink salmon in the high seas samples.

Results of classifying pink salmon of unknown origin obtained on the high seas are presented in Table 7 as percentage of fish in each sample classified into the two morphotypes. Samples are listed by longitude from east to west.

Only four of the 33 samples have more than 50 percent western Alaska-type fish. These western Alaska-type samples were taken from the following locations: south of the Alaska Peninsula at 53°55′N. and 159°40′W. on July 26, south of the Alaska Peninsula at 53°00′N. and 160°00′W. on July 25, the eastern Bering Sea at 59°00′N. and 175°00′W. on June 27 and south of Adak Island at 51°31′N. and 176°42′W. on July 27. The last two samples were classified as 40.5 and 34.6 percent eastern Kamchatka-type fish. Since these values are higher than we would expect in random sampling of pure North American stocks, it is possible that they contain some Asian fish or misclassified North American fish. In a similar manner, North American fish may be present in the sample taken at 57°00′N. and 180°, which was classified as 38.6 percent western Alaska-type.

The three samples from the North Pacific Ocean containing more than 50 percent western Alaska-type fish were taken south of Adak Island on July 27 and south of the Alaska Peninsula on July 25 and July 26. Table 8 shows that approximately 97.0 percent of the eastern Kamchatkan pink salmon coastal catch occurred by August 1. Since the majority of eastern Kamchatkan pink salmon migrated to the coastal areas by late July, we would not expect large numbers of eastern Kamchatkan pink salmon in the samples taken south of Adak Island on July 27 and south of the Alaska Peninsula on July 25 and July 26.

With the possible exception of two samples taken south of Kamchatka at 152°58′E. and 150°27′E., the remaining samples appear to be eastern Kamchatka-type fish (Fig. 1). Their percentages of western Alaska-type range only as high as 22.6, which is no greater than the misclassification expected in pure Asian samples.

One assumption for use of the discriminant function is that the high seas collections originate from areas represented by the samples composing the morphotypes. This assumption cannot be completely satisfied for samples taken from outside the high seas tagging area and pink salmon from these samples may have originated from other areas. For example, it seems possible that large numbers of fish from Asian spawning areas other than eastern Kamchatka were present in the collections obtained south of Kam-

Table 7. Classification of 1959 pink salmon high seas samples to western Alaskan or eastern Kamchatkan morphotypes.

Map number[1]	Location		Date	Sample size	Percent classified	
					Western Alaskan	Eastern Kamchatkan
16	53°55′N,	159°40′W	7/26	50	96.0	4.0
17	53°00′N,	160°00′W	7/25	38	94.7	5.3
18	51°00′N,	169°56′W	7/5	52	15.4	84.6
19	52°00′N,	169°53′W	7/4	43	20.9	79.1
20	53°58′N,	170°01′W	7/2	23	8.7	91.3
21	53°18′N,	170°00′W	7/3	54	9.3	90.7
22	59°00′N,	170°00′W	6/27	42	59.5	40.5
23	52°59′N,	175°00′W	6/21	64	10.9	89.1
24	56°00′N,	176°00′W	6/24	69	15.9	84.1
25	55°00′N,	176°00′W	6/23	53	9.4	90.6
26	54°00′N,	176°00′W	6/22	49	18.4	81.6
27	51°31′N,	176°25′W	6/15	41	14.6	85.4
28	51°31′N,	176°42′W	7/27	26	65.4	34.6
29	51°23′N,	176°45′W	6/14	32	9.4	90.6
30	52°38′N,	178°47′W	6/22	40	12.5	87.5
31	60°00′N,	180°	6/30	64	12.5	87.5
32	58°00′N,	180°	6/28	60	15.0	85.0
33	57°00′N,	180°	6/27	44	38.6	61.4
34	56°00′N,	180°	6/26	20	10.0	90.0
35	55°00′N,	180°	6/25	63	14.3	85.7
36	54°00′N,	180°	6/24	86	16.3	83.7
37	53°30′N,	180°	6/13	23	0.0	100.0
38	52°59′N,	179°55′E	6/23	48	14.6	85.4
39	48°00′N,	175°00′E	5/25	45	22.2	77.8
40	55°00′N,	175°00′E	7/15	84	13.1	86.9
41	48°57′N,	169°29′E	5/26	23	17.4	82.6
42	48°48′N,	168°36′E	7/15	22	18.2	81.8
43	52°32′N,	163°48′E	7/5	34	8.8	91.2
44	48°31′N,	162°31′E	6/15	23	17.4	82.6
45	44°54′N,	161°03′E	5/30	22	4.5	95.5
46	47°20′N,	155°53′E	7/10	53	22.6	77.4
47	45°24′N,	152°58′E	6/30	33	33.3	66.7
48	43°48′N,	150°27′E	6/14	42	28.6	71.4

[1] Numbers refer to sampling locations in Figure 1.

Table 8. Percentage of the yearly catch of pink salmon taken from June to September in 1959 from the coastal areas of eastern Kamchatka in Asia and central and western Alaska in North America.

Area	Month			
	June	July	August	September
	Percent	*Percent*	*Percent*	*Percent*
Eastern Kamchatka[1]	0.3	96.7	2.0	1.0
Central and western Alaska[2]	4.0	45.6	49.8	0.6

[1] Data submitted to the INPFC by VNIRO—INPFC Doc. 363.

[2] INPFC Statistical Yearbook 1959.

chatka. Two samples taken from 152°58′E. and 150°27′E. were classified 66.7 and 71.4 percent into the Asian morphotype. These figures are slightly lower than we would expect from pure eastern Kamchatkan fish. Since fish tagged in this area were recovered from Okhotsk Sea and western Kamchatkan spawning regions (INPFC, 1961), it is possible that these fish were from the Okhotsk Sea or western Kamchatka.

SUMMARY AND CONCLUSIONS

Six morphological characters, four from scales and two from radiographs of ossified structures, were used in a discriminant function analysis to determine continent of origin of pink salmon from the North Pacific Ocean and Bering Sea in 1959. Samples were collected from the high seas and the principal spawning areas of Alaska and British Columbia.

The destination of the pink salmon taken from Aleutian and Bering Sea waters was assumed to be eastern Kamchatka in Asia and western or central Alaska in North America. Consequently, morphological characters from eastern Kamchatkan and Alaskan fish were used to compute continental morphotypes.

The morphological characters were examined for differences between morphotype means and for conformity to the statistical requirements of a discriminant function. The results of these examinations indicated that the characters could be used in a discriminant function analysis that would classify fish taken on the high seas to most probable continent of origin on the basis of their resemblance to one or the other morphotype.

A discriminant function was calculated that correctly classified 85.7 percent of the eastern Kamchatkan and western Alaskan fish. When the high seas collections were classified with this analysis, only four of the 33 samples had more than 50 percent western Alaska-type fish. In the Bering Sea, eastern Kamchatkan fish were dominant in all samples taken west of 170° W. longitude. However, one sample taken at 59° N. and 170° W. had 60 percent western Alaska-type fish. In the North Pacific Ocean, eastern Kamchatkan fish were dominant in all samples taken west of 170°W. with one exception. That sample was taken at 51°31'N. and 176°42'W. on July 27. It was classified as 65.4 percent western Alaska-type fish.

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APPENDICES

Appendix A. Pink Salmon Samples Collected in 1959 and Processed for Morphological Characters.

Inshore Samples

Area	Location	Date	Sample size
Northwestern Alaska	Unalakleet River	7/10	44
"	"	7/12	31
Alaska Peninsula	Ivanof Bay	7/29	3
"	"	7/30	72
"	Coal Bay Stream	8/1	75
"	Hook Bay	8/13	59
Kodiak Island	Uyak Bay	8/6	75
"	Olga Bay	8/9	76
Prince William Sound	Sheep Bay	7/5	74
Petersburg	Sanborn Canal	8/3	73
"	Mole Harbor	8/9	75
Ketchikan	Robinson Creek	8/18	75
"	Halibut Bay	8/16	75
Skeena River	Point Edward	8/14	75
Rivers Inlet	Fitzhugh Sound	8/14	75
Fraser River	Steveston	9/1	74
Hokkaido Island	Yubetsu River	8/17	75

High Seas Samples

Vessel	Location	Date	Sample size
	United States Research Vessels		
Commander	52°12′N, 173°43′E	7/10	13
Pioneer	48°00′N, 175°00′E	5/25	100
"	52°47′N, 171°00′E	6/4	4
"	55°00′N, 171°00′E	6/8	1
"	53°30′N, 180°	6/13	44
"	52°38′N, 178°47′W	6/22	69
"	52°59′N, 179°55′W	6/23	103
"	54°00′N, 180°	6/24	119
"	55°00′N, 180°	6/25	100
"	56°00′N, 180°	6/26	36
"	57°00′N, 180°	6/27	74
"	58°00′N, 180°	6/28	99
"	60°00′N, 180°	6/30	119
"	58°00′N, 175°00′E	7/4	105
"	55°00′N, 175°00′E	7/15	124
"	54°00′N, 175°00′E	7/16	24
"	51°54′N, 174°00′E	7/19	10
"	51°30′N, 175°00′E	7/22	3
"	50°30′N, 175°00′E	7/23	3
"	51°31′N, 176°42′W	7/27	36
"	51°31′N, 176°40′W	7/28	5
"	51°29′N, 176°38′W	7/29	36
"	50°00′N, 175°00′W	8/6	2
"	49°05′N, 170°10′W	8/12	1

Continued . . .

APPENDIX A. (Continued)

Vessel	Location	Date	Sample size
Tordenskjold	53°17′N, 165°35′W	5/25	3
”	51°56′N, 169°39′W	5/27	9
”	51°41′N, 171°57′W	5/28	13
”	51°00′N, 180°	6/2	10
”	49°59′N, 179°57′W	6/3	9
”	49°03′N, 179°56′W	6/4	104
”	49°01′N, 175°04′W	6/7	87
”	51°32′N, 176°31′W	6/12	57
”	51°32′N, 176°34′W	6/14	21
”	51°31′N, 176°25′W	6/15	105
”	52°59′N, 175°00′W	6/21	100
”	54°00′N, 176°00′W	6/22	97
”	55°00′N, 176°00′W	6/23	100
”	56°00′N, 176°00′W	6/24	100
”	57°00′N, 175°00′W	6/25	24
”	59°00′N, 170°00′W	6/27	87
”	58°00′N, 170°00′W	6/28	3
”	55°59′N, 170°00′W	6/30	60
”	55°01′N, 170°03′W	7/1	11
”	53°58′N, 170°01′W	7/2	57
”	53°18′N, 170°00′W	7/3	100
”	52°00′N, 169°53′W	7/4	104
”	51°00′N, 169°56′W	7/5	98
”	53°30′N, 165°00′W	7/11	39
”	52°58′N, 164°58′W	7/12	18
”	50°02′N, 165°00′W	7/15	2
”	47°01′N, 160°02′W	7/19	1
”	48°02′N, 160°00′W	7/20	1
”	49°55′N, 160°05′W	7/22	12
”	50°57′N, 159°55′W	7/23	19
”	51°57′N, 159°58′W	7/24	19
”	53°00′N, 160°00′W	7/25	93
”	53°55′N, 159°40′W	7/26	72
	Japanese Research Vessels		
Wakashio Maru	48°00′N, 170°00′E	5/26	5
”	48°07′N, 165°11′E	6/8	7
”	48°45′N, 162°37′E	6/11	9
”	49°31′N, 159°59′E	6/17	49
”	51°00′N, 159°28′E	8/8	3
”	51°25′N, 163°00′E	8/17	2
Tenyo Maru	57°58′N, 174°17′E	7/5	14
”	57°56′N, 170°00′E	7/17	23
”	51°31′N, 176°27′W	6/12	2
”	51°23′N, 176°45′W	6/14	52
”	51°23′N, 176°34′W	6/15	10
	Canadian Research Vessels		
Key West	50°00′N, 145°00′W	5/18	9
”	50°00′N, 145°00′W	5/19	19
”	53°00′N, 160°00′W	6/14	67
”	53°00′N, 160°00′W	6/24	36
”	50°00′N, 160°00′W	6/27	40
”	50°00′N, 160°00′W	6/28	43

Continued . . .

Appendix A. (Continued)

Vessel	Location	Date	Sample size
	Japanese Landbased Fishery		
Takuyo Maru	43°41′N, 157°10′E	5/20	72
”	44°54′N, 161°03′E	5/30	73
”	43°48′N, 150°27′E	6/14	75
”	45°24′N, 152°58′E	6/30	75
”	47°20′N, 155°53′E	7/10	80
	Japanese Mothership Fishery (Nichiro Fishing Company)		
Yae Maru	48°57′N, 169°29′E	5/26	75
Anshin Maru	51°21′N, 171°20′E	6/5	75
Chokai Maru	48°24′N, 163°55′E	6/15	75
Anshin Maru	49°06′N, 170°52′E	6/25	75
Kaiho Maru	52°32′N, 163°48′E	7/5	75
	Japanese Mothership Fishery (Nippon Suisan)		
Miyajima Maru	48°00′N, 169°12′E	5/27	75
”	46°21′N, 168°06′E	6/5	75
”	48°31′N, 162°31′E	6/15	70
”	56°49′N, 173°22′E	7/5	75
”	48°48′N, 168°36′E	7/15	75

APPENDIX B-1. TESTS FOR SELECTING A SCALE AXIS

The circuli on pink salmon scales form concentrically around a central platelet or focus. Although circulus counts and scale measurements can be taken along any axis from the focus, Clutter and Whitesel (1956) found that the counts and measurements vary with choice of angle for sockeye salmon. Therefore, if circuli counts or measurements are to be used as morphological characters, it is necessary to (1) select a specified scale axis and (2) choose this axis consistently.

The worker who made the measurements was tested to determine whether he was consistent in selecting a specified axis. The following methods of selecting an axis were examined: (1) the longest radius from the center of the focus to the annulus and (2) the longest radius from the focus to the seventeenth circulus. Ten scales from Unalakleet River fish and ten scales from eastern Kamchatkan fish were used in the tests. The identification of each scale was concealed from the worker. The angle of the axis that the worker selected was recorded from two separate observations for each method. The differences in angle between the first and second observations were examined with *t*-tests (Snedecor, 1956).

The results of these tests are shown in Appendix B-1 Table 1. Since the differences in angle were not significant at the five percent level, it was concluded that the worker could select the specified axis with each method. However, the mean square of the differences was 8.56 with the longest radius to the annulus and only 2.22 with the longest radius to the seventeenth circulus. Consequently, the scale axis used in this study was the longest radius from the center of the focus to the seventeenth circulus.

APPENDIX B-1 TABLE 1. Results of *t*-tests to determine if differences in angle occur when selecting a scale axis.

	Method of selecting the axis	
	Longest radius from focus to seventeenth circulus	Longest radius from focus to annulus
Number of scales	20	20
Mean of differences (degrees)	−0.25	−0.08
Mean square of differences	2.22	8.56
Standard deviation of differences	1.49	2.93
t-value from test	−0.76	−0.12
$t_{0.05}$ with 19 *d.f.*	±2.09	±2.09

Appendix B-2. Tests for Differences Between Readings of Scale Characters

The worker who made the measurements was tested to discover whether he could accurately repeat the necessary circuli count or measurement for each scale character.

Fifty scales were randomly sampled from each of the following 1959 samples: (1) Uyak Bay, (2) Ivanof Bay, (3) Unalakleet River, (4) United States research vessel *Pioneer* at 58°00′N., 175°00′E., and (5) Japanese mothership fishery vessel *Miyajima Maru* at 56°49′N., 173°22′E. The identification of each scale was concealed from the worker during the test. The character values were recorded from each scale from two separate observations. In each of the readings, the order of observation for the 250 scales was determined by random selection. The differences between the first and second readings were examined with a *t*-test (Snedecor, 1956).

The results of this examination are found in Appendix B-2 Table 1. Since the differences between the readings of the scales were not significant at the five percent level for any character, it was concluded that the worker could accurately repeat a previous circuli count or measurement.

Appendix B-2 Table 1. Results of *t*-tests to determine if differences occur between two readings of the scale characters.

	Scale character			
	Number of circuli in first half	Number of circuli in second half	Number of circuli in second sixth	Width (mm.) of narrowest three circuli
Number of scales	250	250	250	250
Mean of differences	−0.0280	−0.0520	+0.0220	−0.0520
Mean square of differences	0.2522	0.6117	0.1672	0.7242
Standard deviation of differences	0.5022	0.7821	0.4089	0.8510
Standard error of differences	0.0318	0.0495	0.0258	0.0538
t-value from test	−0.8805	−1.0505	+0.8527	−0.9665
$t_{0.05}$ with 249 *d.f.*	±1.971	±1.971	±1.971	±1.971

Appendix B-3. Mean Values of the Scale Characters Using Seven Different Radial Lines

The mean values of the scale characters were examined along radial lines different from the selected scale axis.

Data were collected on the following radial lines: (1) 60° to the left of the scale axis, (2) 40° to the left of the scale axis, (3) 20° to the left of the scale axis, (4) the scale axis, (5) 20° to the right of the scale axis, (6) 40° to the right of the scale axis and (7) 60° to the right of the scale axis. Ten scales from Kodiak Island fish and ten scales from eastern Kamchatkan fish were used. The scales were taken from the preferred body position on the left side of the fish.

The results of this examination are shown in Appendix B-3 Table 1. Although the sample sizes are small, it is apparent that the counts and measurements vary with change in position of the radial line. Generally, the circulus counts are greatest from 20° to 40° on the right side of the selected scale axis. The narrowest-three-circuli measurement is greatest on the scale axis. These results indicate that circulus counts and scale measurements should be taken along a particular radial line to obtain scale characters of the greatest consistency.

Because of the variation in mean value of circulus counts and scale measurements with different radial lines, the morphological characters used to classify the 1959 collections to continent of origin were taken only along the following three radial lines: (1) the scale axis, (2) 7.5° to the right of the scale axis when the first line could not be used and (3) 7.5° to the left of the scale axis when the first and second lines were not usable.

Appendix B-3 Table 1. Means and variances of the scale characters taken along seven different radial lines.

Character	Radial line	Kodiak Island		Eastern Kamchatka	
		Mean	Variance	Mean	Variance
Number of circuli in first half	60° left of scale axis	11.10	1.43	9.45	1.52
	40° left of scale axis	11.50	0.94	9.95	1.64
	20° left of scale axis	11.90	0.66	10.10	1.21
	Scale axis	11.90	0.66	10.35	1.78
	20° right of scale axis	12.00	0.44	10.35	1.72
	40° right of scale axis	11.45	1.30	9.80	2.18
	60° right of scale axis	11.15	0.45	9.35	2.22
Number of circuli in second half	60° left of scale axis	12.95	1.30	10.75	0.57
	40° left of scale axis	13.00	1.78	10.65	1.17
	20° left of scale axis	12.70	1.01	10.00	1.11
	Scale axis	12.50	1.28	10.15	1.45
	20° right of scale axis	13.30	0.90	11.35	0.84
	40° right of scale axis	13.25	0.68	11.40	1.16
	60° right of scale axis	12.65	1.34	10.85	1.45
Number of circuli in second sixth	60° left of scale axis	4.10	0.43	3.20	0.62
	40° left of scale axis	4.10	0.27	3.25	0.46
	20° left of scale axis	4.10	0.16	3.45	0.25
	Scale axis	3.90	0.27	3.45	0.19
	20° right of scale axis	4.15	0.28	3.55	0.30
	40° right of scale axis	4.10	0·27	3.40	0.60
	60° right of scale axis	4.20	0.23	3.40	0.93
Width of narrowest three circuli	60° left of scale axis	7.6	1.2	9.5	0.5
	40° left of scale axis	9.1	2.3	10.0	1.8
	20° left of scale axis	10.5	1.6	10.5	0.5
	Scale axis	10.8	2.3	11.7	1.6
	20° right of scale axis	9.7	1.8	11.1	2.3
	40° right of scale axis	9.0	1.8	10.3	2.0
	60° right of scale axis	7.9	1.4	9.3	2.0

Appendix B-4. Variation in Mean Value of Characters Observed in Scales from Different Body Positions on a Pink Salmon

Research workers have observed differences in the scales of *Oncorhynchus* sampled from various parts of the fish. Variation of scale characters with respect to body position has been observed by Hayashi (1957) on pink salmon and Clutter and Whitesel (1956) on sockeye salmon. Therefore, each scale character in this study was examined to determine if differences occur when scales are taken from several positions on an individual fish.

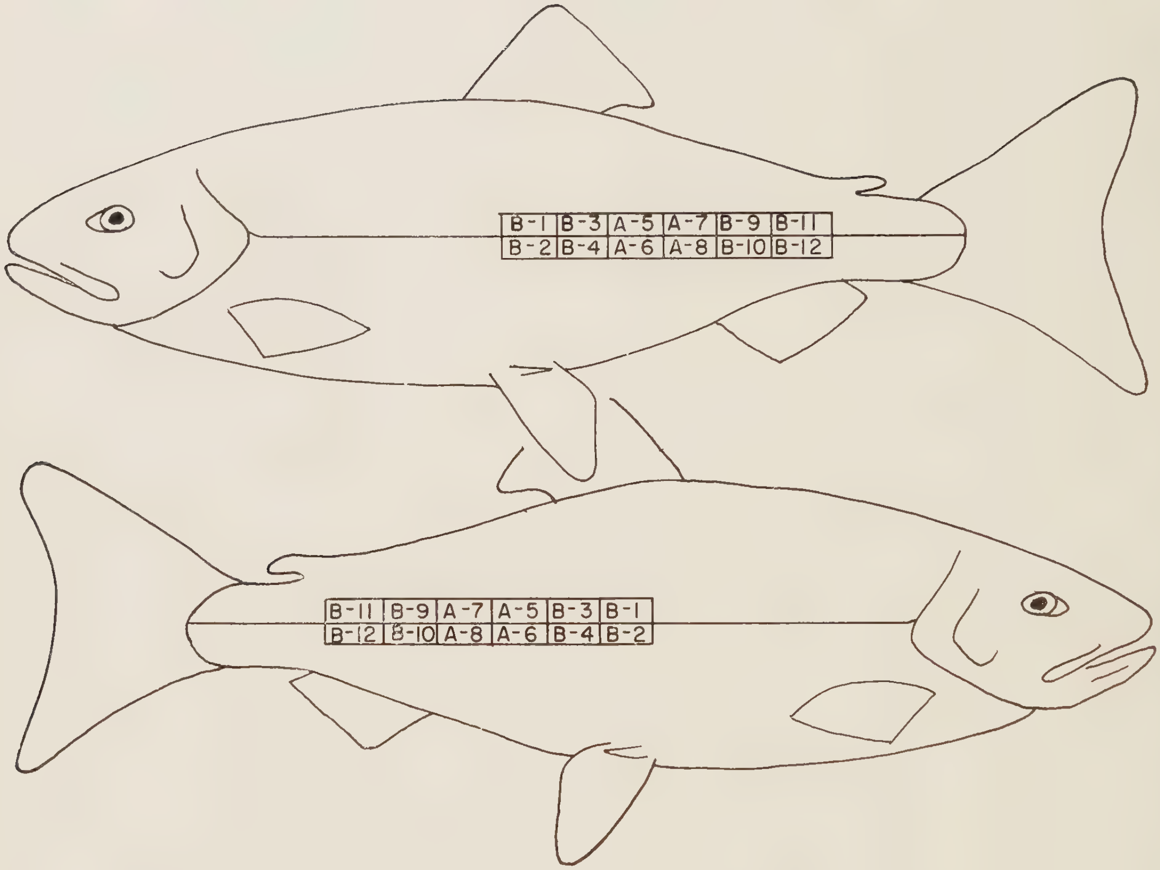
Scales were taken from the International North Pacific Fisheries Commission A and B sampling areas (Appendix B-4 Figure 1) on the left and right sides of a pink salmon caught in Karluk Lagoon on July 28, 1960. These areas were subdivided into four zones of four vertical scale rows and 15 horizontal scale rows. Fifteen scales were randomly sampled from each zone of 60 scales.

The results of this examination are found in Appendix B-4 Table 1. All characters except the narrowest three measurements follow a pattern similar to that of number of circuli in the first half of the first ocean zone where higher mean values occur in the posterior sampling zones. The mean values of the narrowest three measurements were less variable between the anterior and posterior sampling zones. In a similar manner, higher mean values were observed on the right side of the fish in all characters other than the narrowest three measurements. The mean values of the narrowest three measurements were less variable between sides.

Because of the variation in mean value of characters observed in scales from different body positions, scales from only the preferred body position were used to classify the 1959 collections to continent of origin. Further study was conducted to determine if the mean values of the characters were the same in preferred scales from both sides of the fish within samples. The results of that study are in Appendix B-5.

Appendix B-4 Table 1. Means and variances of scale characters from different body positions on a pink salmon.

Body position (See App. B-4 Fig. 1)			Scale character							
			Number of circuli in first half		Number of circuli in second half		Number of circuli in second sixth		Width of narrowest three circuli	
Side	Area	Zone	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
Right	B	1	10.7	0.25	10.1	0.45	3.6	0.15	9.2	0.74
		2	10.8	0.27	10.4	0.30	3.6	0.05	9.7	0.64
		3	10.9	0.48	10.5	0.41	3.7	0.10	9.1	1.50
		4	11.0	0.36	10.3	0.24	3.8	0.13	9.3	0.95
	A	5	11.0	0.16	10.4	0.39	3.7	0.10	9.0	1.14
		6	11.0	0.66	10.3	0.42	3.8	0.17	9.2	1.46
		7	11.7	0.27	10.5	0.23	3.9	0.17	9.0	0.29
		8	11.4	0.25	10.6	0.39	4.0	0.16	9.4	0.69
	B	9	11.5	0.36	10.9	0.26	3.8	0.10	9.4	0.83
		10	11.1	0.35	10.7	0.67	3.8	0.10	9.5	0.55
		11	11.4	0.20	11.0	0.41	3.8	0.06	9.5	0.55
		12	11.4	0.28	11.2	0.45	3.9	0.07	9.5	0.41
Left	B	1	10.6	0.23	10.2	0.63	3.5	0.14	9.9	0.55
		2	10.3	0.32	9.9	0.53	3.5	0.20	9.5	1.55
		3	10.8	0.28	10.4	0.44	3.6	0.22	9.5	0.55
		4	10.7	0.35	9.8	0.31	3.6	0.10	9.4	0.54
	A	5	11.1	0.57	10.4	0.61	3.8	0.07	9.3	0.68
		6	10.8	0.31	10.0	0.29	3.7	0.17	8.9	0.92
		7	11.3	0.38	10.7	0.14	3.7	0.14	9.1	0.92
		8	11.0	0.71	10.2	0.74	3.7	0.10	9.5	0.69
	B	9	11.3	0.27	10.8	0.35	3.7	0.13	9.5	0.55
		10	11.4	0.58	10.5	0.45	3.8	0.14	9.3	0.67
		11	11.2	0.20	10.6	0.53	3.7	0.06	9.3	0.50
		12	11.4	0.44	10.7	0.60	3.7	0.10	9.1	0.64



Appendix B-4 Figure 1. Scale sampling locations on the left and right sides of a pink salmon.

Appendix B-5. Tests for Difference in Mean Value of Characters from Preferred Body Position Scales Between Right and Left Side of Body

In Appendix B-4, the mean values of the scale characters were examined on the left and right sides of one pink salmon. Higher values were observed on the right side in all characters other than the narrowest three measurements. This condition was examined further to determine if the mean values differ between sides within samples.

Two spawning area samples were used. They were obtained from Ivanof Bay on August 6, 1960, and from Karluk Lagoon on July 28, 1960. Scales were taken from the preferred body position on the left and right sides of the fish. The character means and variances were computed for each side in each sample. The differences in mean value between the right and left sides were examined with a *t*-test (Snedecor, 1956).

The results of this test are found in Appendix B-5 Table 1. The differences in mean values between sides were not significant at the five percent level for any character. Since no difference was observed within samples, scales from the preferred body position on either the left or right side of the fish were used to classify the 1959 collections to continent of origin. Scales from the left side were preferred. If the left side scale was missing or damaged, the scale from the right side was used.

Appendix B-5 Table 1. Results of *t*-tests to determine if differences occur in mean value of characters from preferred body position scales between right and left sides of pink salmon within samples.

Inshore area	Scale character	Side of fish	Sample size	Mean	Variance	Mean difference	Pooled variance	*t*-value from test
Ivanof Bay Aug. 6, 1960	Number of circuli in first half	Left	36	11.6250	0.7912	0.0000	0.6410	0.0000
		Right	84	11.6250	0.5776			$t_{0.05}$ with 118 *d.f.* $= \pm 1.982$
	Number of circuli in second half	Left	36	11.1528	1.7689	0.1528	1.4441	0.6383
		Right	84	11.0000	1.3072			$t_{0.05}$ with 118 *d.f.* $= \pm 1.982$
	Number of circuli in second sixth	Left	36	3.9722	0.2992	−0.0516	0.2832	−0.4868
		Right	84	4.0238	0.2765			$t_{0.05}$ with 118 *d.f.* $= \pm 1.982$
	Width of narrowest three circuli	Left	36	10.5000	2.0857	0.4762	1.8217	1.7709
		Right	84	10.0238	1.7104			$t_{0.05}$ with 118 *d.f.* $= \pm 1.982$
Karluk Lagoon July 28, 1960	Number of circuli in first half	Left	81	11.2901	0.9992	−0.0599	0.8738	−0.4189
		Right	90	11.3500	0.7610			$t_{0.05}$ with 169 *d.f.* $= \pm 1.976$
	Number of circuli in second half	Left	81	11.3827	0.9079	−0.0784	1.2559	−0.4571
		Right	90	11.4611	1.5687			$t_{0.05}$ with 169 *d.f.* $= \pm 1.976$
	Number of circuli in second sixth	Left	81	3.6296	0.3861	−0.0260	0.3237	−0.2989
		Right	90	3.6556	0.2677			$t_{0.05}$ with 169 *d.f.* $= \pm 1.976$
	Width of narrowest three circuli	Left	81	10.9630	2.2612	0.0074	1.9688	0.0345
		Right	90	10.9556	1.7059			$t_{0.05}$ with 169 *d.f.* $= \pm 1.976$

APPENDIX C. PERCENTAGES OF PINK SALMON COLLECTED IN 1959 HAVING USABLE MORPHOLOGICAL CHARACTERS

	Sample size	Character (usable percentage in sample)		
		Scales	Branchiostegals	Vertebrae
Inshore samples	1106	60.8	98.8	96.0
High seas samples				
United States research vessels	2865	54.4	97.5	93.8
Japanese research vessels	176	40.1	96.0	94.3
Canadian research vessels	214	0.0	86.4	94.9
Japanese landbased vessels	375	45.1	98.9	97.3
Japanese mothership fishery	745	35.6	98.7	94.5

APPENDIX D. WITHIN RACE VARIABILITY TESTS

The objective of Appendix D was to determine the effect of within race variation on counts and measurements obtained from the morphological characters collected from spawning streams in 1959. Two main sources of variation were examined: differences in counts between sexes and the relationship between length of fish and magnitude of counts.

Before the high seas collections can be classified by means of their morphological characters, it must be determined if the counts observed in the high seas samples are typical of those found in the races to which they belong. Since within race variation can bias the classification, the effect of possible sources of within race variation on each character was examined.

APPENDIX D-1. TESTS FOR SEXUAL DIFFERENCES IN MORPHOLOGICAL CHARACTERS

Each character was tested to determine if differences occurred in counts or measurements between sexes. An approximate two-way analysis of variance design with unequal numbers of observations in the cells (Snedecor, 1956), allows the effects of spawning area, sex and interaction to be determined in a single test. If a significant sexual difference was found, the unbiased estimate of the difference was calculated (Snedecor, 1956). Spawning area samples with 20 or more specimens of each sex were used in these tests (Appendix D-1 Table 1).

The results of the analysis of variance tests are found in Appendix D-1 Table 2. No significant interaction effects were found. One significant sexual difference was found in number of scale circuli in the first half. The unbiased estimate of the difference was 0.237 circuli higher in males. Since the discriminant function analysis was calculated with eastern Kamchatkan and western Alaskan fish, eastern Kamchatkan and western Alaskan samples were also tested for sexual differences in number of circuli in the first half. The results of this test are found in Appendix D-1 Table 3. Although the unbiased estimate of the difference was 0.132 circuli greater in males than in females, the sex effect was not significant at the five percent level. None of the other five morphological characters exhibited significant differences.

APPENDIX D-1 TABLE 1. Spawning area samples used in tests for sexual differences in morphological characters.

Area	Location
Alaska Peninsula	Ivanof Bay
" "	Coal Bay Stream
" "	Hook Bay
Kodiak Island	Uyak Bay
" "	Olga Bay[1]
Petersburg	Sanborn Canal
"	Mole Harbor[1]
Ketchikan	Robinson Creek[1]
"	Halibut Bay[1]

[1] Since 20 or more usable scales from specimens of each sex were not available for study, this sample was not used to determine if differences occurred in scale characters between sexes.

Appendix D-1 Table 2. Results of two-way analysis of variance tests for each character between sex of fish and spawning area.

Source of variation	Sum of squares	*d. f.*	Mean squares	Mean squares individual basis
	Number of circuli in first half			
Area	9.4399	4	2.3600**	
Sex	0.1793	1	0.1793*	
Interaction	0.1469	4	0.0367	1.0186
Error	212.9660	279	0.0275	0.7633
	Number of circuli in second half			
Area	7.6609	4	1.9152**	
Sex	0.0783	1	0.0783	
Interaction	0.0735	4	0.0184	0.5107
Error	255.3790	279	0.0330	0.9153
	Number of circuli in second sixth			
Area	0.8260	4	0.2065**	
Sex	0.0342	1	0.0342	
Interaction	0.0248	4	0.0062	0.1721
Error	77.9950	279	0.0101	0.2796
	Width of narrowest three circuli			
Area	1.5491	4	0.3873*	
Sex	0.2325	1	0.2325	
Interaction	0.0617	4	0.0154	0.4274
Error	611.0000	279	0.0789	2.1900
	Number of branchiostegal rays			
Area	0.9190	8	0.1149**	
Sex	0.0438	1	0.0438	
Interaction	0.0548	8	0.0069	0.2283
Error	278.5000	636	0.0132	0.4379
	Number of vertebrae			
Area	3.3584	8	0.4198**	
Sex	0.0487	1	0.0487	
Interaction	0.2096	8	0.0262	0.8371
Error	462.1000	610	0.0237	0.7575

** Significant at the one percent level.
* Significant at the five percent level.

Appendix D-1 Table 3. Results of two-way analysis of variance test for number of circuli in the first half between sex of fish and discriminant function samples.

Source of variation	Sum of squares	*d. f.*	Mean squares	Mean squares individual basis
Samples	6.5480	6	1.0913*	
Sex	0.0690	1	0.0690	
Interaction	0.0765	6	0.0128	0.3656
Error	268.0310	421	0.0223	0.6367

* Significant at the one percent level.

Appendix D-2. Examination of the Effect of Fish Length on Morphological Characters

It is not always possible to collect specimens with length typical of their race, for it is known that certain types and sizes of fishing gear will select fish by length. If the morphological characters being studied are correlated with length, biased samples will occur when specimens of non-representative length are collected. To examine this possibility, examinations of correlation between fish length and each of the characters were made. Correlation coefficients were computed for each sample. These *r*-values were tested to determine if they were obtained from a common population correlation. The resulting average correlation coefficients were tested for significance. Where a common population correlation was found, the average *r* and percent variation of the character attributable to the variation in length of fish were calculated. Stream samples from all spawning areas with at least 48 specimens were used in these tests with sexes combined. The two samples collected from Unalakleet River on different dates were combined after each morphological character count and measurement was tested to determine if differences occurred between times of sampling.

The results of these examinations are found in Appendix D-2 Table 1. Each character was found to have a common population correlation. The only character with a significant average *r* was the width of the narrowest three circuli. The average *r* value was 0.1524 and the percent variation in width of the narrowest three circuli attributable to the variation in length of fish was only 2.3226 percent.

The results of this examination indicated that length of fish was a negligible source of variation on the counts or measurements of all six morphological characters.

Appendix D-2 Table 1. Results of examinations for correlation of characters with length of fish, chi-square tests for common correlation, average *r*'s and percent variation of characters attributable to the variation in length of fish.

		Characters					
Location	*N*	Vertebrae *r*	Branchiostegal rays *r*	Number circuli first half *r*	Number circuli second half *r*	Number circuli second sixth *r*	Width of narrowest three circuli *r*
Unalakleet River	72	−0.0650	0.0036				
	63			−0.0795	0.0200	−0.2238	0.2535
Ivanof Bay	69	0.0090	−0.0525				
	65			−0.0597	0.0309	0.0097	0.2752
Coal Bay	72	0.1582	0.1012				
	67			0.2031	0.0236	0.1516	0.1844
Hook Bay	54	0.0900	0.0336				
	49			0.0959	0.1884	0.1264	−0.0750
Uyak Bay	74	0.0439	0.1459				
	60			0.1215	0.0637	0.0770	0.0334
Sanborn Canal	69	−0.0043	0.0370				
	48			0.1471	−0.1845	0.2325	0.1803
Olga Bay	76	−0.2436	−0.0022				
Sheep Bay	73	0.0709	0.2673				
Mole Harbor	65	0.1466	0.0306				
Robinson Creek	67	0.2366	0.0482				
Halibut Bay	70	−0.0215	−0.1193				
X^2		11.7496	7.8525	3.9633	3.3669	7.2866	4.9640
Average *r*		0.0338	0.0400	0.0582	0.0259	0.0527	0.1524*
Percent variation attributable to length		0.1142	0.1600	0.3387	0.0671	0.2777	2.3226

* Significant at the one percent level.

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Editor

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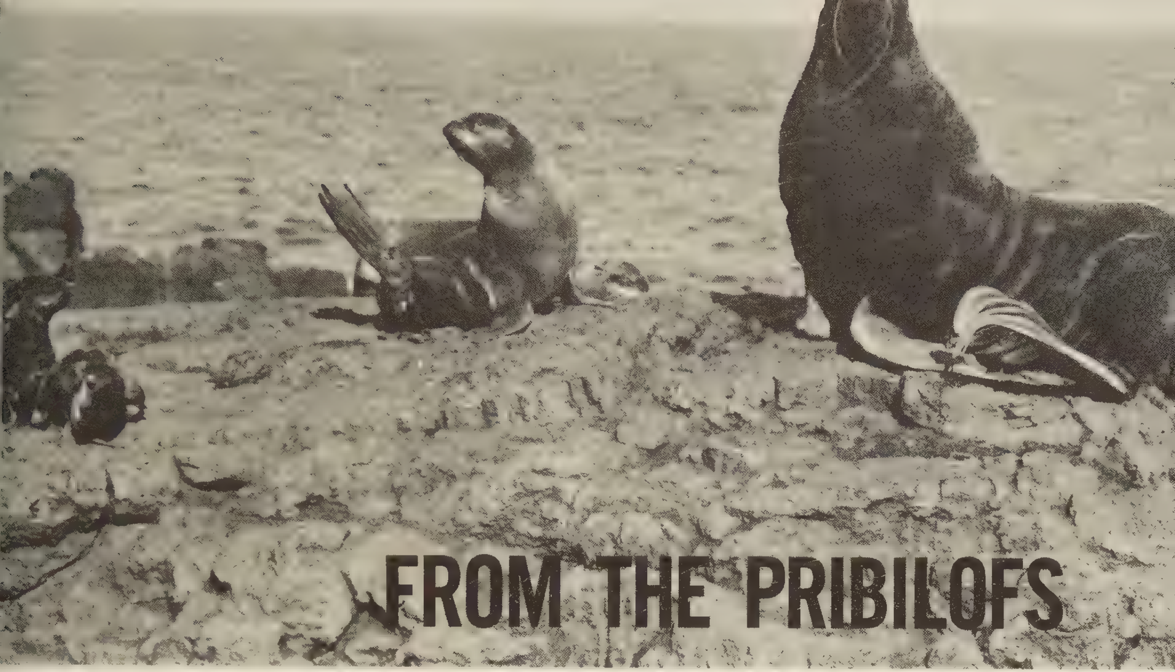
COVER

James Flamingo, *Phoenicoparrus jamesi*

The James Flamingo is not only the smallest but also the rarest of the four forms of New World flamingos. For many years this bird, native to the Andes of Peru, Bolivia, Chile and Argentina at elevations up to 17,000 feet, was believed extinct. However, in 1960, William Conway, director of the New York Zoological Garden, brought the first living specimens out of South America, captured on Laguna Colorada in the Bolivian Andes. It was not until 1964 that further specimens reached North America, a pair entering the San Diego Zoo's collection. This is the second time these birds have been exhibited in the United States. Our present collection of flamingos, all found at the Dryer Lagoon, consists of five of the world's six living forms.

ORTHERN FUR SEALS FROM THE PRIBILOFS



s, females, and males of Northern Fur Seals differ markedly in size. Photo by author, St. Paul Island, Alaska

Richard S. Peterson[1]

HE NEW NORTHERN Fur Seals, *Callor- us ursinus,* on display at the San Diego Zoo e brought from Alaska last October. By cour- y of the Bureau of Commercial Fisheries, ted States Fish and Wildlife Service, they e caught at St. Paul Island, one of the Pri- fs, in the Bering Sea north of the Aleutians.

. crew of native Aleuts, under Lavrenty petin, an islander who has assisted for many rs in the government's seal conservation pro- m, selected the animals for the Zoo from ong the thousands on the beaches. The gov- ment had approved catching two small seals, or three years old, and one "bull," about en or eight. The Zoo had supplied crates, sent he island on the weekly mailplane.

avrenty has caught fur seals for the San go Zoo before, including the first albino seal ' captured, "Pinky," in 1948. So he knew it was wanted. He quickly spotted two fine- ing young seals, and by scattering a large group on the beach, the Aleuts sorted them out. With cowboy-like dexterity, they tossed lassos over their heads and brought them back to the shipping crates.

But catching the bull was another matter. These animals are five times as large as adult females, and fully grown may reach 650 pounds. The extreme size difference, or sexual dimorphism, probably is related to fur seals' social and mating behavior, for big males seem to have an advantage. Although seen in many animals, including man, the sexual dimorphism in size of fur seals is the greatest of any mammal.

The bulls are very powerful, and not particularly afraid of man; so confining one was a problem. The Aleuts know that the big "ataghan" attack men, and several were reluctant to try

---

[1] *The author has spent parts of the past three years at the Pribilof Islands studying fur seals. He is associated with the Department of Pathobiology, Johns Hopkins University, Baltimore, and the Bureau of Commercial Fisheries, Fish and Wildlife Service, Seattle.*

At home in the Zoo, the Northern Fur Seals can choose between a workout in the long salt water pool or a dip
the refrigerated fresh water.

handling one. Lavrenty realized from his years of experience, however, that most attacks occur during the breeding season, in June and July. After some time he convinced his assistants. A

A Northern Fur Seal pup, about six weeks old, scratches its head with one back flipper.

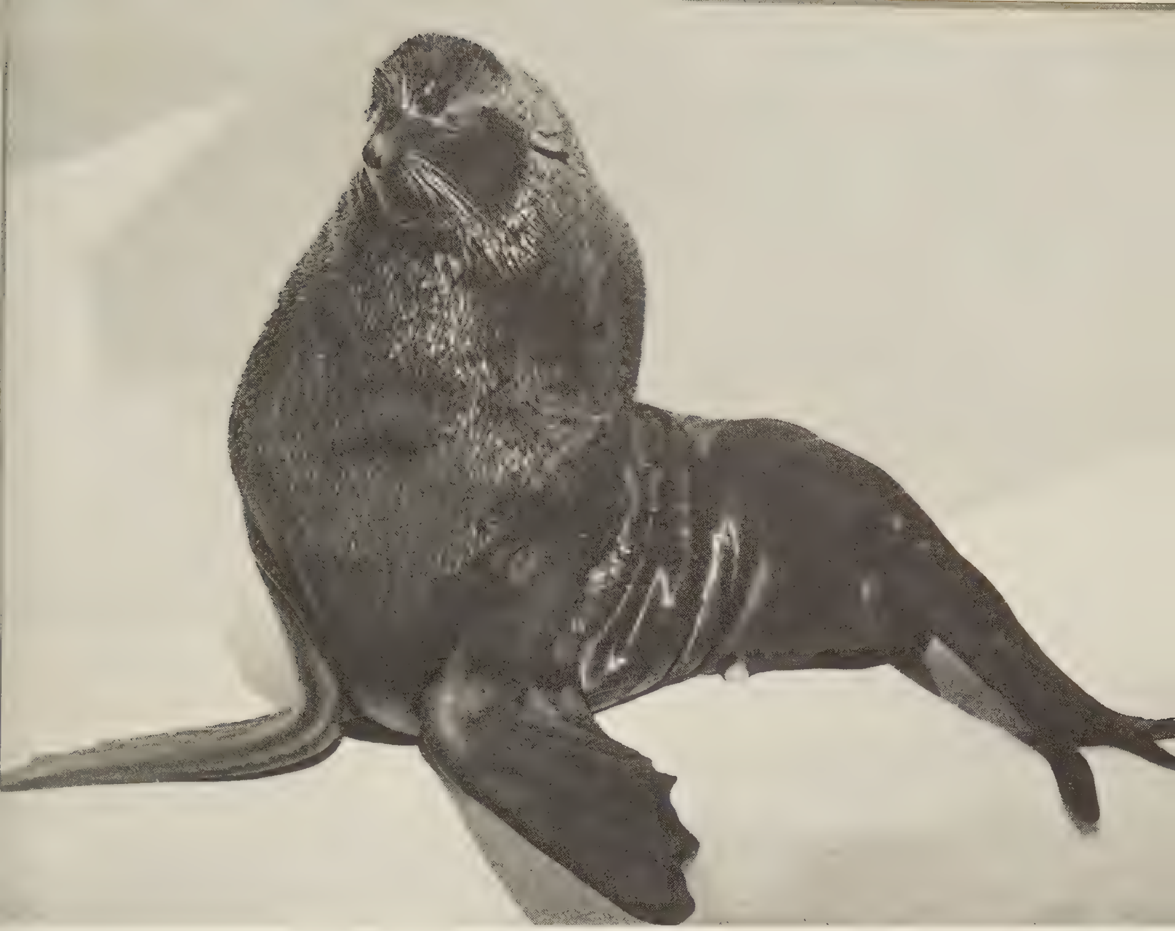
Photo by author, St. Paul Island, Alaska

healthy young bull was selected, and seve
ropes were tossed around it. By herding so
other seals along with it, the bull finally w
walked to the crate. After much prodding, it w
confined and the gate nailed shut.

The bull was flown from Alaska by jet. Le
than 36 hours intervened from the time the ca
was nailed shut until the marine mammal w
free again in a pool at the San Diego Zoo.
may have been a little dismayed by the qui
change in weather, for the San Diego tempe
ture was in the 80's on the day of arrival, thou
snow fell the day previous on St. Paul Isla

Bulls have an unusual, musky odor, possib
useful when defining their territories on t
breeding grounds. At the Zoo, it might be
tectable only if the bull "roars" in your face; b
confined in the passenger compartment of t
Reeve Aleutian Airways plane on the way
Anchorage, it was overwhelmingly strong.
one Aleut commented after landing, the t
was "umaiukna chuckna"—very smelly.

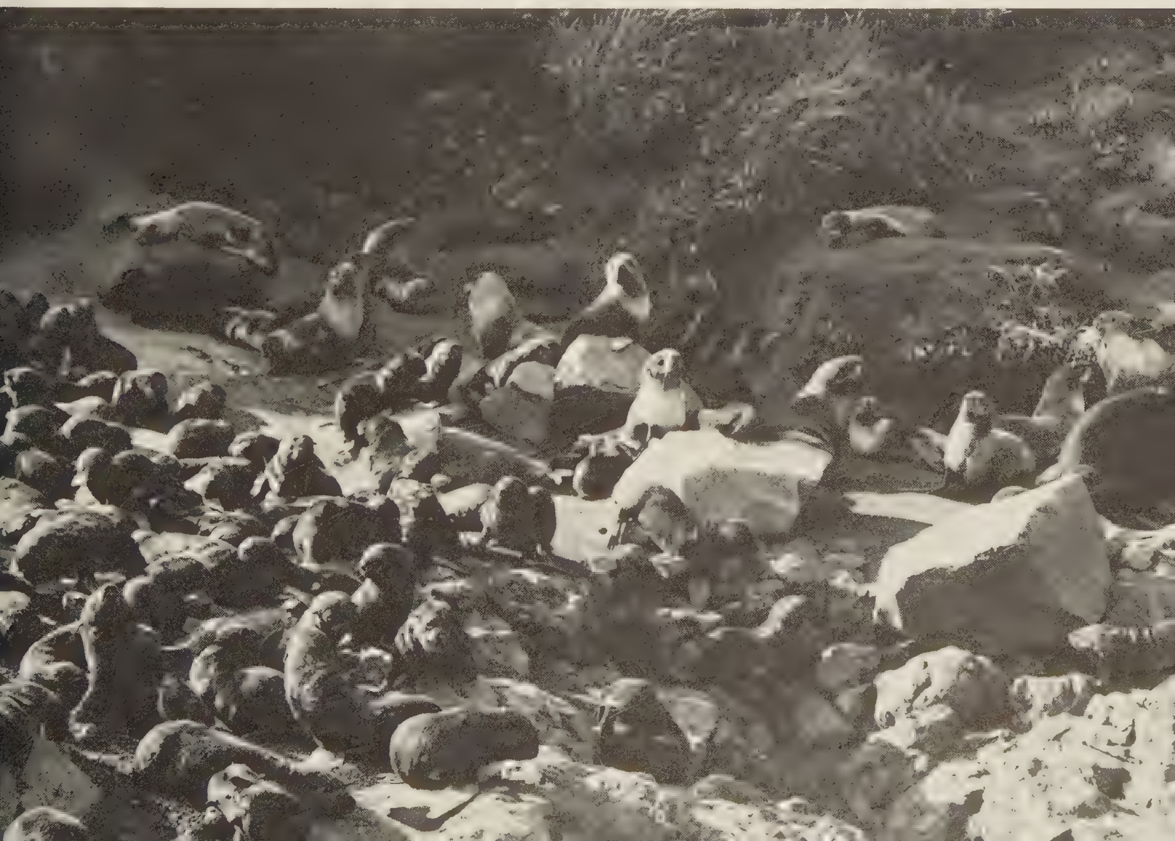
Quietly watching the fur seals in the S
Diego Zoo for a few minutes (or hours) will ra
questions in anyone's mind. What is signified
the unusual, chortled noises? How can they sle



The Northern Fur Seal bull was caught napping in the Southern California sun.

beachmaster at the extreme right collects his harem. Young pups are asleep at the left in the rugged rookery ged with tufts of vegetation.

Photo by author, St. Paul Island, Alaska



afloat without drowning? Are the flippers used for propulsion, or just steering? Can seals live out of the water? How can they control body heat, or live in salt water?

Biologists like myself often wonder these same questions. Because Northern Fur Seals are so valuable, for "Alaska Seal" furs, there has been considerable need for studying them as part of development of a sound conservation program. So, a variety of basic research projects have been undertaken, sponsored by the Bureau of Commercial Fisheries. Many important questions now have been answered, though others remain as intriguing as ever.

The same sort of questions must have occurred to Georg Wilhelm Steller, the great biologist, when he was shipwrecked on Bering Island in 1739. For in spite of the privations of near-starvation and illness, he apparently spent weeks studying fur seals and writing detailed notes. The section on the seals in his posthumous book, *De Bestiis marinis* (1751) is indeed a classic.

When describing the noises made by a bull seal, Steller said, "These animals have three different kinds of speech. To pass away the time while they lie upon land, they cry out, and their voice is not at all different from the lowing of cows when deprived of their calves. In battle, they roar and growl like a bear, and if they get the victory they utter a very sharp and often repeated note like our common crickets. But when wounded or overcome by their enemies they groan terribly or hiss like a cat or sea otter."

In captivity, the bull may make some of these noises, which are now known to have specific meanings or purposes. When chasing the younger seals at the Zoo, the cricketlike noise or "whicker" should be obvious. It is heard at the breeding grounds when a bull patrols his territory, and seems to warn nearby trespassers – perhaps with the feeling of "victory," as Steller believed. The "lowing" or roar is a mild sort of threat, heard when wandering bulls or a man pass near the breeding grounds. It might be heard at the Zoo. "Growling" may be heard if the bull sniffs at the younger animals, or tries to push them about. In the wild, it signifies a bull's interest in mating.

Another unusual vocal pattern of bulls was aptly described by Dr. George A. Bartholomew of the University of California at Los Angeles his report on fur seal behavior. It is heard du ing territorial disputes, and is characterized "two animals violently charging toward ea other and then throwing themselves flat on the bellies, sliding to a halt . . . and puffiing at ea other like a small locomotive." Such "puffin probably won't be heard unless the Zoo gets second bull.

Fur seals come ashore on a few isolated islan primarily to give birth, raise their young, a breed. They spend all the rest of the year at se Their dense fur, under the outer hair, traps a and may help them to float while sleeping. Th become so unconscious at sea that it is possib to prod them with a paddle before they awake if you approach quietly in a small boat.

During the breeding season, the seals adhe to a rigid social pattern which requires th breeding bulls to stay on land for many wee Until last summer, we were not sure just ho long individual bulls stayed out of the wat Bulls marked with bleached letters in their f from previous years were carefully watched fro an observation blind throughout the summe The longest observed time ashore was 77 day and most bulls stayed at least 30 days. Appa ently, they live off the thick blanket of blubb stored under the skin during winter. As f thirst, perhaps land is only slightly more an than the salty sea. Most physiologists now b lieve that seals must get the fresh water th need from the tissues of fish they eat.

Life on land poses other difficulties for the seals. They show signs of distress and try to g into the water if the air temperature is mu above 50° F. This probably is one reason th breed on the cool, foggy Pribilofs. Their soci life is surprisingly well synchronized to t climate and seasons there: In May and Jur when temperatures are in the 40's, the bu come on land and stake out territories on t ancient breeding grounds. Then, within a fe days, around the first of July, the half-milli pregnant females, or cows, converge on t islands. The temperatures now reach the 50 too hot for the adults to stay on land mu longer, but ideal for the poorly insulated ne born pups. Thus, within a week or two early July, the pups are born, breeding is complete and most of the adult seals begin to leave for se

ch cow returns every eight or ten days to
e her pup (usually just one, though a few
s have been seen). One question that has
puzzled observers is how the females recog-
their own young among the thousands of
ling, black pups. Through a series of experi-
ts, the process has been narrowed down to
e or four factors:

cation—the cow and pup both learn the
ay of the land" well enough to return to
e same place at each feeding;

calization—the cow and pup learn each
her's voices so they can recognize one an-
her even amid the din of thousands of
her seals;

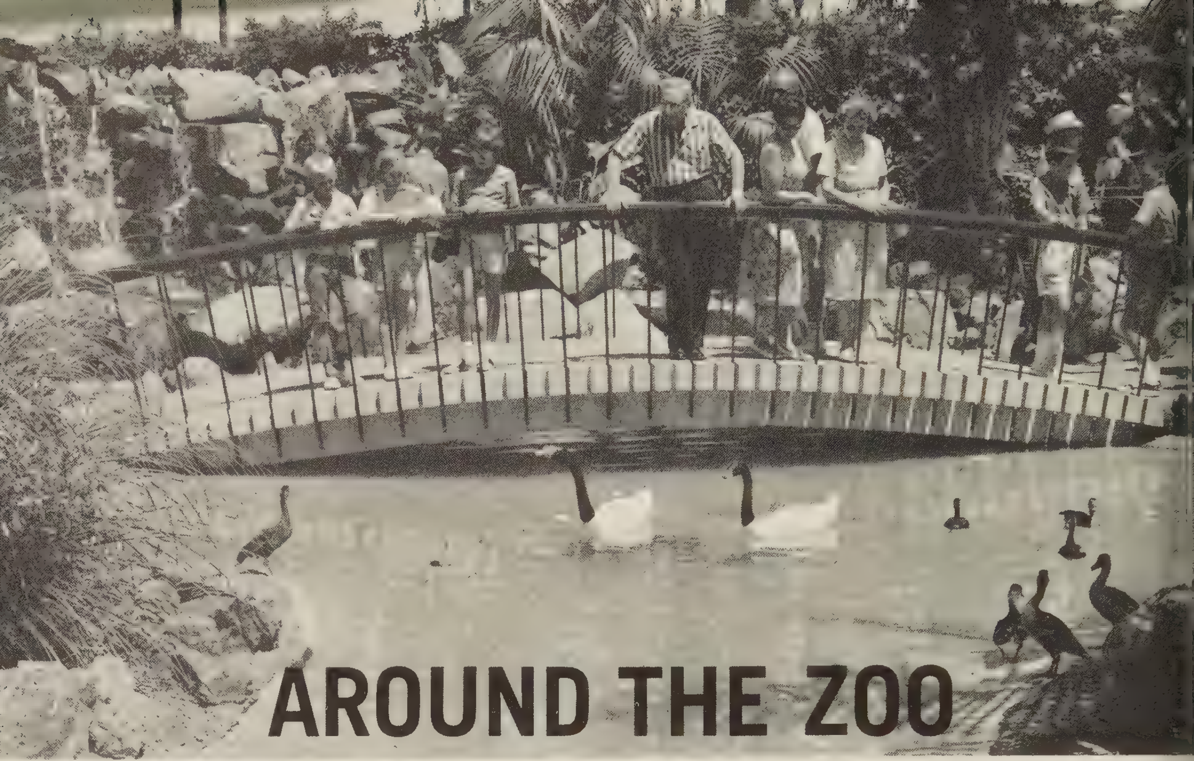
ght—pups seem to need to see their mothers, although sound alone will attract them, as from a tape recorder;

Smell—cows and pups always touch noses when reuniting, so perhaps an individual odor may be important, though that is difficult to know.

Compared to most species of seals, Northern Fur Seals are highly social, at least during the breeding season. Apparently this is due to an inability to breed in the water coupled with the problems of life on land, requiring elaborate social organization if breeding is to occur and the species is to be perpetuated. This sociality may or may not be evident in the Zoo. It will be interesting to compare the seals' behavior in captivity and watch for such differences.

A bull Northern Fur Seal watches over his harem. Young pup seals are sleeping in the foreground.

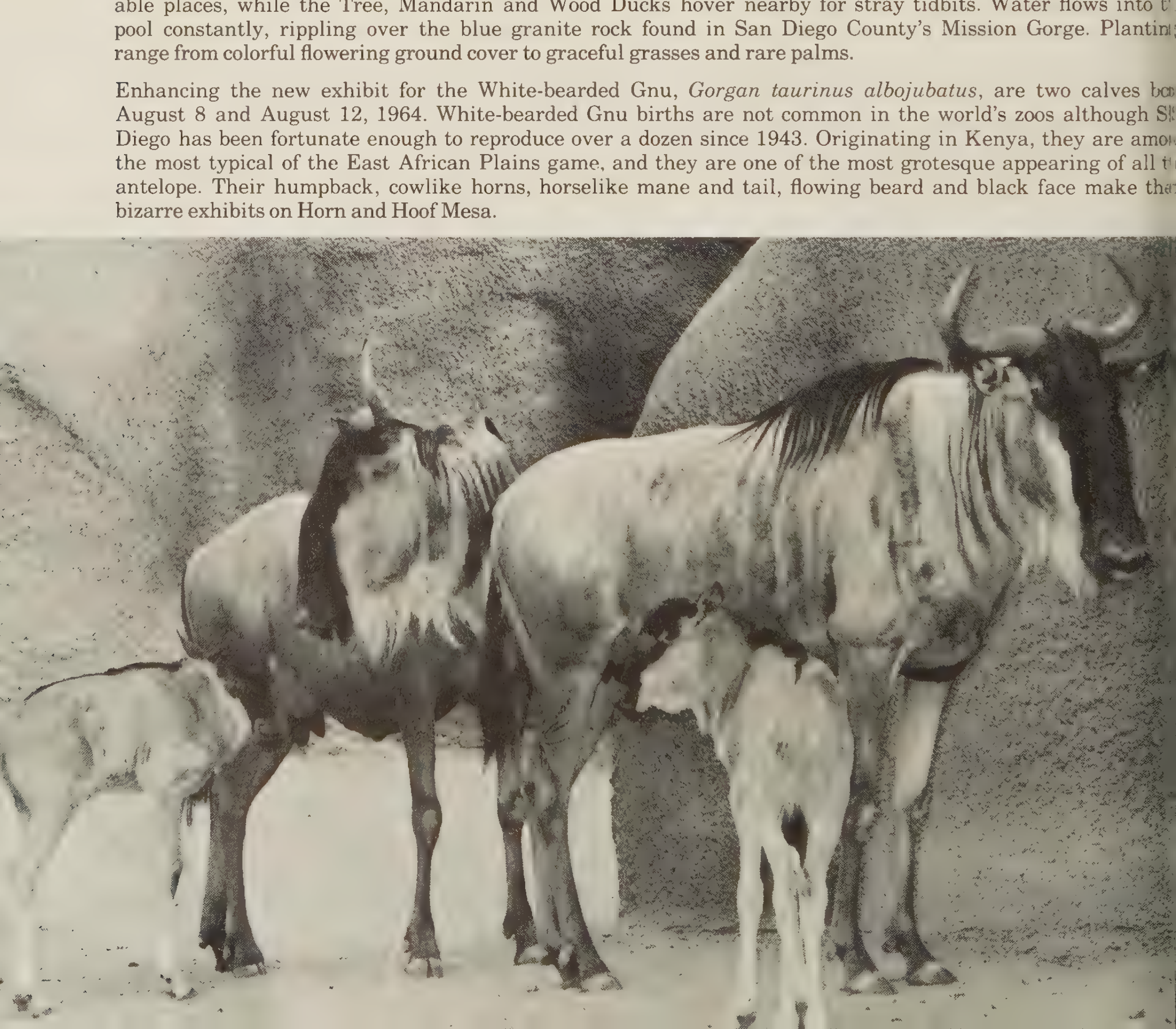
Photo by author



AROUND THE ZOO

The decorative arc bridge of the restaurant terrace lagoon is a vantage point for feeding its waterfowl re dents. Usually the Black-necked Swans turn hopeful eyes toward visitors and maneuver into the most fav able places, while the Tree, Mandarin and Wood Ducks hover nearby for stray tidbits. Water flows into t pool constantly, rippling over the blue granite rock found in San Diego County's Mission Gorge. Plantin range from colorful flowering ground cover to graceful grasses and rare palms.

Enhancing the new exhibit for the White-bearded Gnu, *Gorgan taurinus albojubatus*, are two calves b August 8 and August 12, 1964. White-bearded Gnu births are not common in the world's zoos although S Diego has been fortunate enough to reproduce over a dozen since 1943. Originating in Kenya, they are amo the most typical of the East African Plains game, and they are one of the most grotesque appearing of all t antelope. Their humpback, cowlike horns, horselike mane and tail, flowing beard and black face make th bizarre exhibits on Horn and Hoof Mesa.



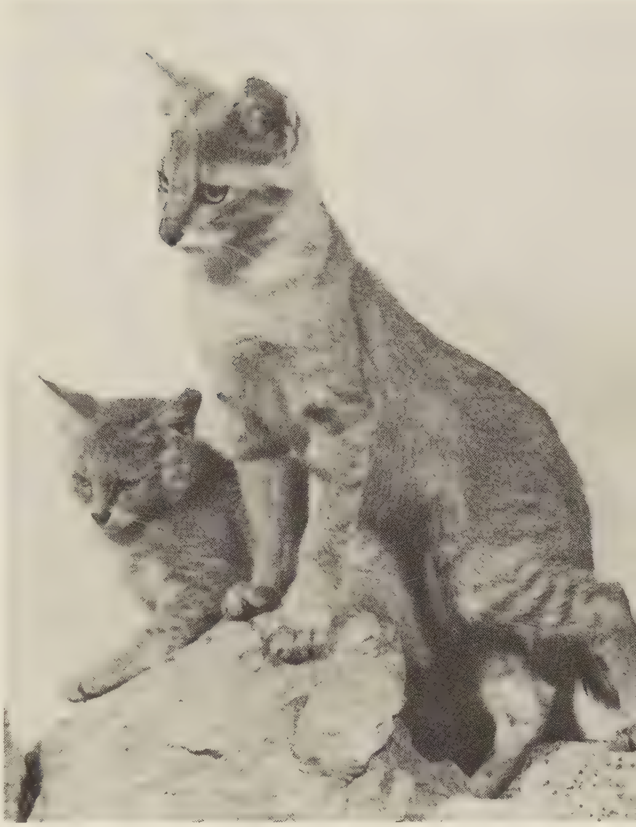
UNGLE CATS

Clyde A. Hill
ASSOCIATE CURATOR

ANGELY, the Jungle Cat often does not
in a jungle. Home for *Felis chaus* stretches
n southeastern Russia, eastern North Africa
the Near East, to India, Ceylon, Burma and
-China. Its habitat may be desert to bush
st, or rivers and marshes, from sea level to
0 feet. Our young Prater's Jungle Cats were
ured near Karachi, West Pakistan.

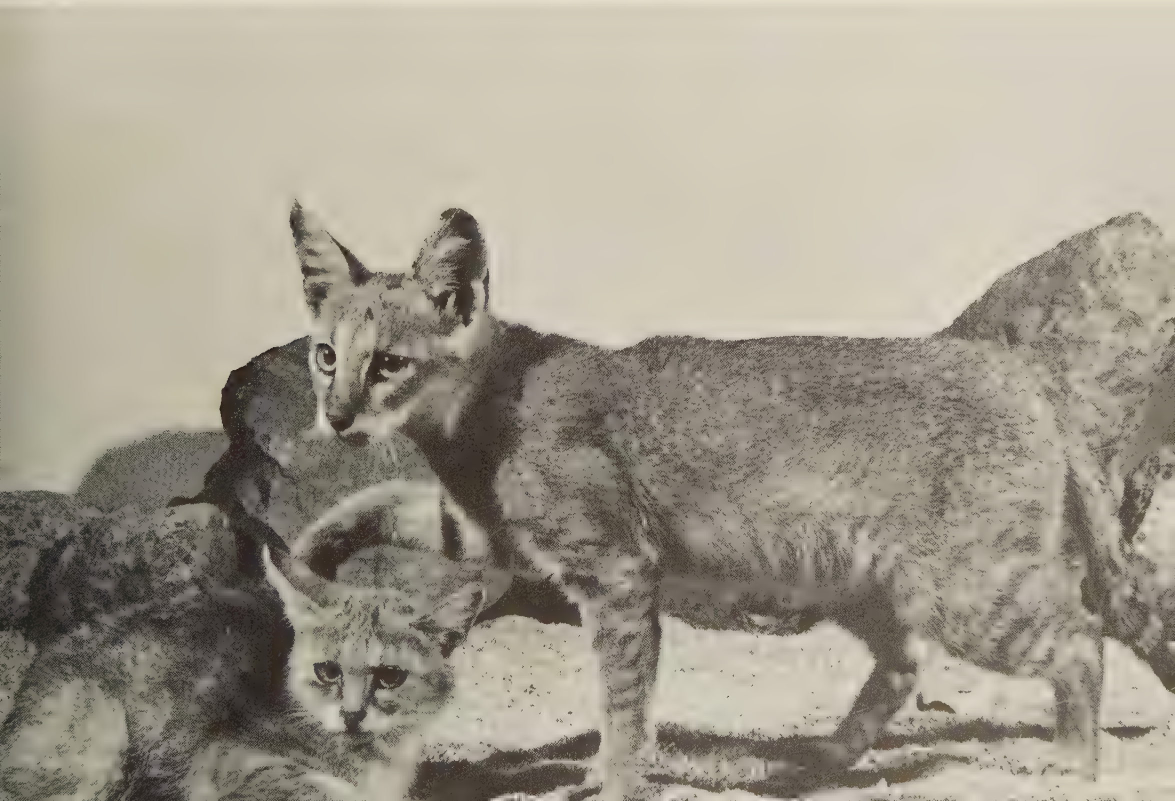
hese cats of moderate size show almost uni-
n color with subdued design throughout.
re are stripes on the cheeks, indistinct bands
sometimes diffuse spots on the body.

s most wary predators, the Jungle Cat be-
es more active after sundown. Its usual gait
short, but not rapid, trot. In hunting, move-
nts are extremely cautious and noiseless, and
ften crouches to the ground. It relies not only
sight and acute hearing for signs of game, but
utilizes the sense of smell. Often the Jungle
will climb trees in search of a meal, for
diet includes various birds as well as small
mmals.



Small brushes of hair tip the long, broad, triangular ears. Photos by Van Nostrand

The lightly ringed tail, approximately one-third of the trunk length, is comparatively short for that of a cat.



STEPPING STONES

to improved incubation and brooding of exotic bird

Laysan Teal ducklings are guarded by two Snow Geese hatched in the month of June. Photo by Van Nostr

Kenton C. Lint, CURATOR

EVERY zoological garden shares responsibility for animal conservation. Much of the wildlife of today and the habitats in which it lives are disappearing.

With the present urgency of bird conservation, modern incubators and brooding facilities have been installed at the San Diego Zoo. Thus it is hoped that new goals may be achieved in our efforts to propagate exotic birds in captivity. Unlike commercial hatcheries working only with domestic species, the Zoo's incubators hatch eggs of many species annually.

In the incubation of the eggs a study of the life history of each species is necessary. Incubation periods may vary slightly within a species, but there are wide differences within families and genera. The longest period we recorded in 1964 was 36 days for rheas, and the shortest, 14 days for Striated Colies. Our experiences with the incubation of hundreds of eggs each seas are carefully recorded. The value of gather data relating to incubation of a single enda gered species is helpful and when the mater on many species is combined, the results a extremely valuable. By studying such inform tion closely, it is hoped that techniques may improved.

Centuries ago the Chinese and Egyptians veloped and successfully used artificial in bators. In contrast with our modern devic many of the primitive hatching units seem v crude, and their operation complex. This art passed on from generation to generation. Th were no thermometers or thermostats for acc rate temperature control. These early hatcher had no recorded incubation periods and knowledge of humidity requirements of the dividual species for reference.

day, in the San Diego Zoo we are using the modern incubators available—a series of glass-fronted units, each with concealed nier temperature adjustment, concealed er, unobstructed floor, display lamp, pro- ed thermometer, extra-sensitive thermostat, simplified vents. All are "forced-air" type bators which combine a fan with a heating ent to provide perfectly even temperature ughout. The eggs are warmed from all sides. ach incubator measures 18¼ inches in h, 32½ inches in length, and 19½ inches in ht. There is sufficient space in the single for a wide range of egg sizes; for example, tray could hold 300 quail, 100 pheasant, hea, or 12 ostrich eggs; or various-sized can be incubated at the same time.

e question often is asked about the necessity he artificial incubation of any egg. There several good reasons for collecting eggs and bating them in machines. In birds as well human beings we find indifferent parents cannot or will not assume family responsi- ies. There are rare birds that refuse to sit heir valuable eggs once they have been de- ted. Because we wish to save these species becoming extinct, we place their eggs in incubators and hatch them artificially.

In the families of pheasants, partridges and turkeys, we find individuals that are eggeaters. If the eggs are not removed from the aviary as soon as laid, they may be broken and consumed.

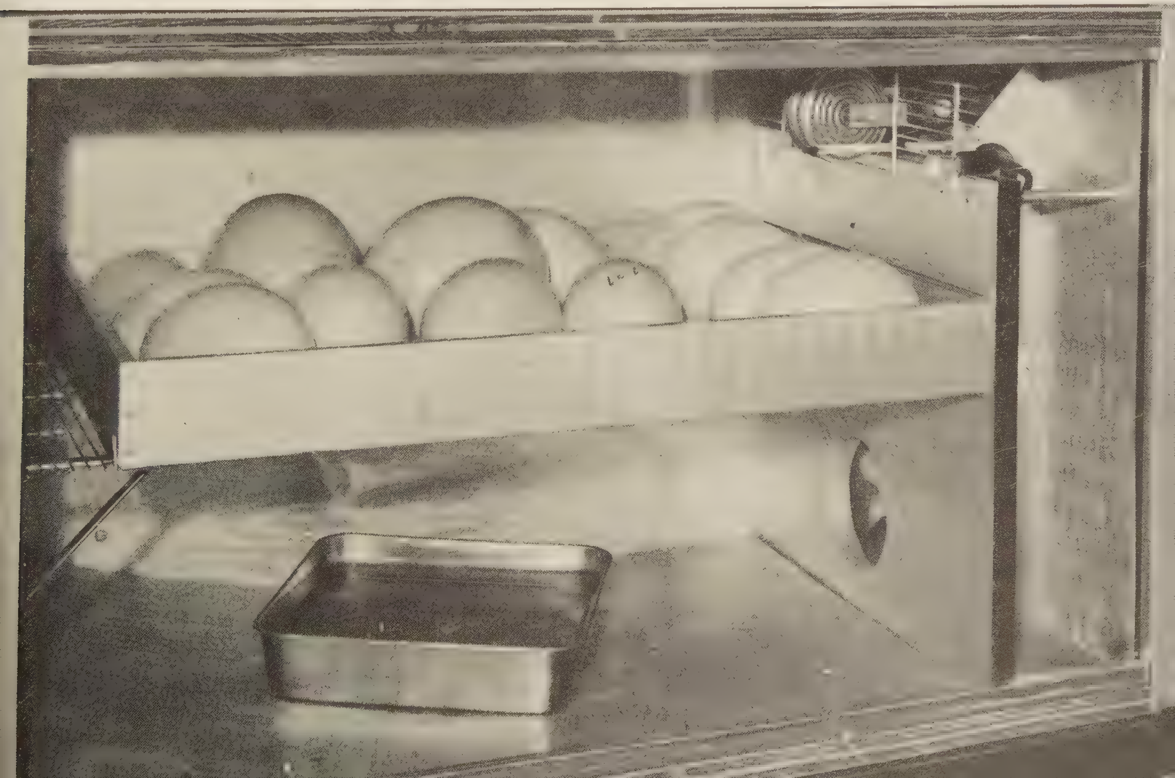
Most collections include birds that refuse to lay eggs in prepared nesting boxes and proceed to deposit their eggs indiscriminately in open areas. Many waterfowl are negligent in this manner—and may lay eggs in shallow pools.

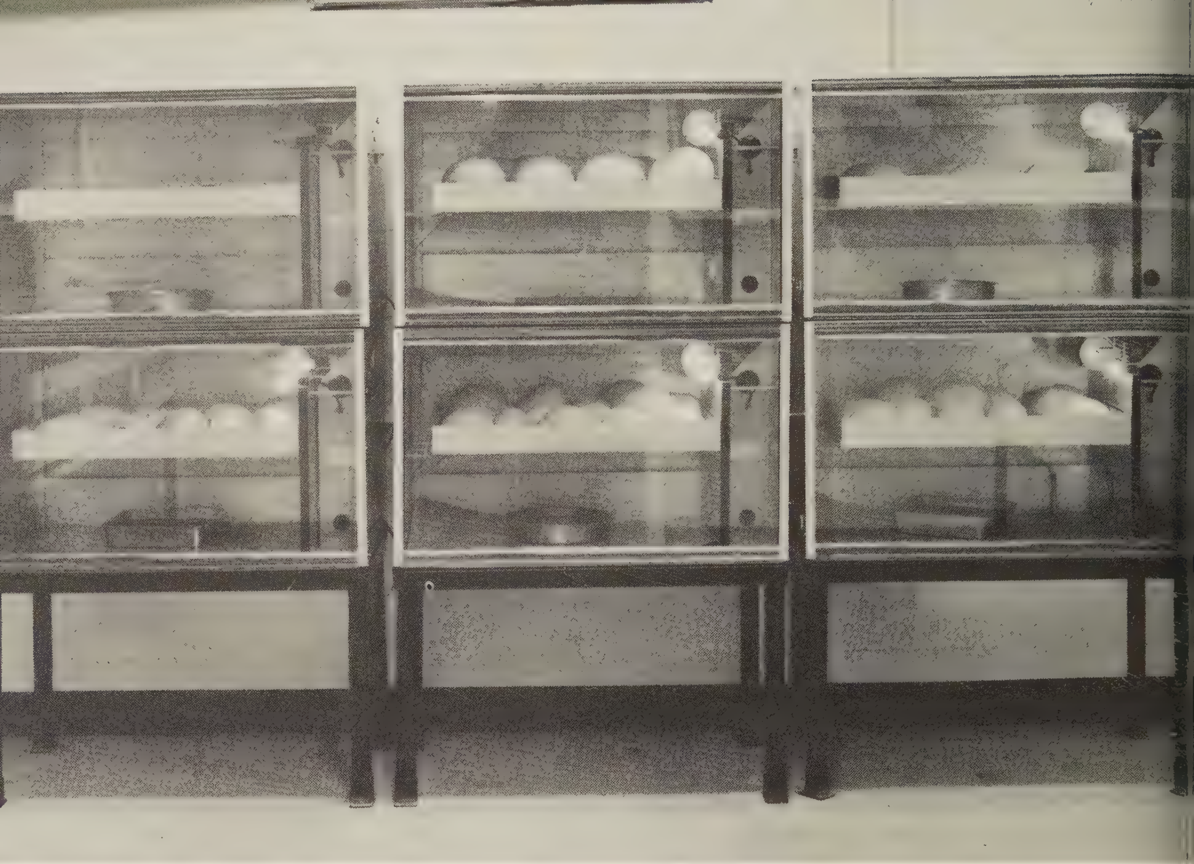
Eggs of certain species of doves and pigeons that persist in laying while perched have been salvaged by catching the eggs in nets placed beneath the roost or perch. We have recovered eggs from roofs of buildings, litter containers, parking lots, even pedestrian paths, and placed them in the incubators.

Many species of birds are induced to lay a second and third clutch of eggs if the first clutch is collected and removed from the breeding pair. The artificial propagation of cranes in captivity is an excellent example of the use of this practice, and results have been most rewarding.

Successful operation of an incubator depends upon the careful control of temperature, humidity, ventilation, egg-turning and egg-testing. The temperature at which eggs are naturally

glass incubator is 18¼ inches wide, 32½ inches long, and 19½ inches high. The egg tray will hold 100 sant, or 15 large ratite (rhea or cassowary) eggs.





(Above) Arranged in a series of six, the glass-fronted incubators feature concealed vernier temperature adju ment, concealed heaters, unobstructed floors, display lamps, protected thermometer, extra-sensitive thermos and simplified vents. *(Below)* Indoor brooders, arranged in a series of three, complement the incubators. E cube, measuring 24 inches, is equipped with a cone heating element, a thermostat, and a 7-watt brooder lig Glass (20 inches long and 5 inches high) across the front of each unit permits observation of the interior. Ab the window there is an opening (20 inches by 3 inches) covered with ¼-inch mesh hardware cloth.

ve) Sliding wooden doors (24 inches wide) provide entrance to the individual brooder units. One may look the room through windows which can be adjusted for ventilation. *(Below)* Nine exercise runs (each $4^1/_2$ feet , 8 feet long and 7 feet high) adjoin the outdoor brooder units. The frame of each run, constructed of galvan- 1-inch pipe, is covered with 1-inch welded wire fabric (16-gauge).

The beautiful eyes in the feather of Germain's Peacock Pheasant appear when chicks are about six weeks of
This dainty bird is native to Annam and Cochin-China.

Photo by Van Nost

incubated is determined primarily by the birds' body temperature, and this varies:

Kiwi	100°F.	Pheasant	106-111°F.
Penguin	102.2°F.	Pigeon	106-109°F.
Ostrich	104°F.	Duck	106-109°F.
Turkey	104°F.	Sparrow	107°F.
Gull	104°F.	Flamingo	108-109°F.
Tinamou	105°F.	Hawk	109°F.
Chicken	105-107°F.	Thrush	112°F.

The degree of heat required in an incubator by eggs of different groups of birds varies; and the correct temperature can be ascertained from an instruction sheet supplied with each type of incubator—or occasionally, for an individual machine. The optimum temperature always must be a relative matter, in that it usually is dependent upon humidity and air movement as well as upon the exact location of the thermometer.

The capacity of air to hold moisture increases rapidly as the temperature rises, and the drier the air in the incubator, the more moisture will be taken from the eggs. In our machines it has been determined that a reading of 61%-65% on the hygrometer (wet bulb reading) is ideal for most species. As might be expected, the eggs of all waterfowl, marsh, shore and wading birds require higher humidity or moisture content in the machines to hatch successfully. The hygrometer should indicate a reading of 82%-85% for best results with these birds.

A Hi-Power transformer-type candler and egg tester permits detection of unproductive eggs. During the incubation period, eggs usually candled for infertility or dead embryos on seventh and fourteenth days. Infertile eggs removed on the seventh day. Eggs in which embryo has died are replaced on the fourteen day of incubation.

The usual practice is to turn eggs in the m chine three or four times during each 24 hou but there is ample experimental evidence th increased turning—up to eight times dail will improve hatchability. Through close obs vation a large amount of information concern the many factors which influence hatchabil may be recorded. The information includes su "standards of good practice" as not shaking eggs while gathering or handling them to act data concerning the hatching time. Or it m reveal little tricks related to the daily 10-min cooling period, frequency of turning, and var tion of temperatures, all factors contributing the degree of success enjoyed while practic the art.

BROODING REQUIREMENTS

Brooding and rearing deal with the growth the chick after hatching, and more specifica with those factors affecting growth that are m or less under the control of the aviculturist breeder. The growth attained by any species w depend upon its inherited ability to grow, food supply, and such environmental factors temperature, air supply, and protection fr parasites and infectious disease.

Iutrient requirements for many exotic spe- s are still little known. Successful brooding ctice is still in the formative stage. Informa- ı gradually is being accumulated season by son. All zoological gardens should secure ther data and publish their findings.

'o increase the success of our breeding pro- m, we have constructed a concrete masonry oder house to accommodate hatchlings after y outgrow small indoor brooders. It contains e individual units, each consisting of a sed brooder room and outdoor exercise run. ch brooder is heated with a 250-watt infra- bulb fitted with a reflector. These lamps radi- an area with concentrated infra-red energy produce a comfort zone in which the chicks y remain warm and contented. By absorbing ficient radiant energy, a chick is able to keep m regardless of how cool the air temperature y be. The radiant energy produces heat on floor and in the litter as well as in the chick, here is no cold object to chill the chick on its derside.

Iatchings this season have been noteworthy ncluded in the total of 81 species are Ocellated keys; Blue Eared, Germain's Peacock, and inhoe Pheasants; Laysan Teal, Hawaiian l Red-crested Pochard Ducks; Chinese nted Quail; and Snow Geese.

Hatched after 28 days of incubation, an American Wood Duck nestles in the keeper's hand when six hours old. Photo by Van Nostrand

'he new brooders have many advantages— there is no large hover to occupy floor space; the chicks are visible at all times and sick chicks can be detected more readily; chicks can select their own temperature zone and are less likely to pile up; labor cost is less than with previous methods because there is less work cleaning, feeding and watering; and the brooding area beneath the unit stays dry. Plasterer's sand is laid over a concrete-covered styrofoam-insulated floor. In this way any danger of fire is eliminated and it is possible to control moisture. However, it should be emphasized that infra-red brooding is not a cure-all for brooding problems.

ıe of these eight week old Swinhoe Pheasants or their offspring one day may return to their native Formosa. s very handsome pheasant was discovered in 1862, but few wild birds remain because of destruction of the forests which they inhabit. Today the world population is estimated to be under 1,000 birds. However, it is nned by conservationists to restock areas in Formosa as soon as adequate protection can be assured.
Photo by Van Nostrand

ZOOLOGICAL SOCIETY OF SAN DIEGO
Box 551
San Diego, California 92112

ZOONOOZ—SEPTEMBER 1964

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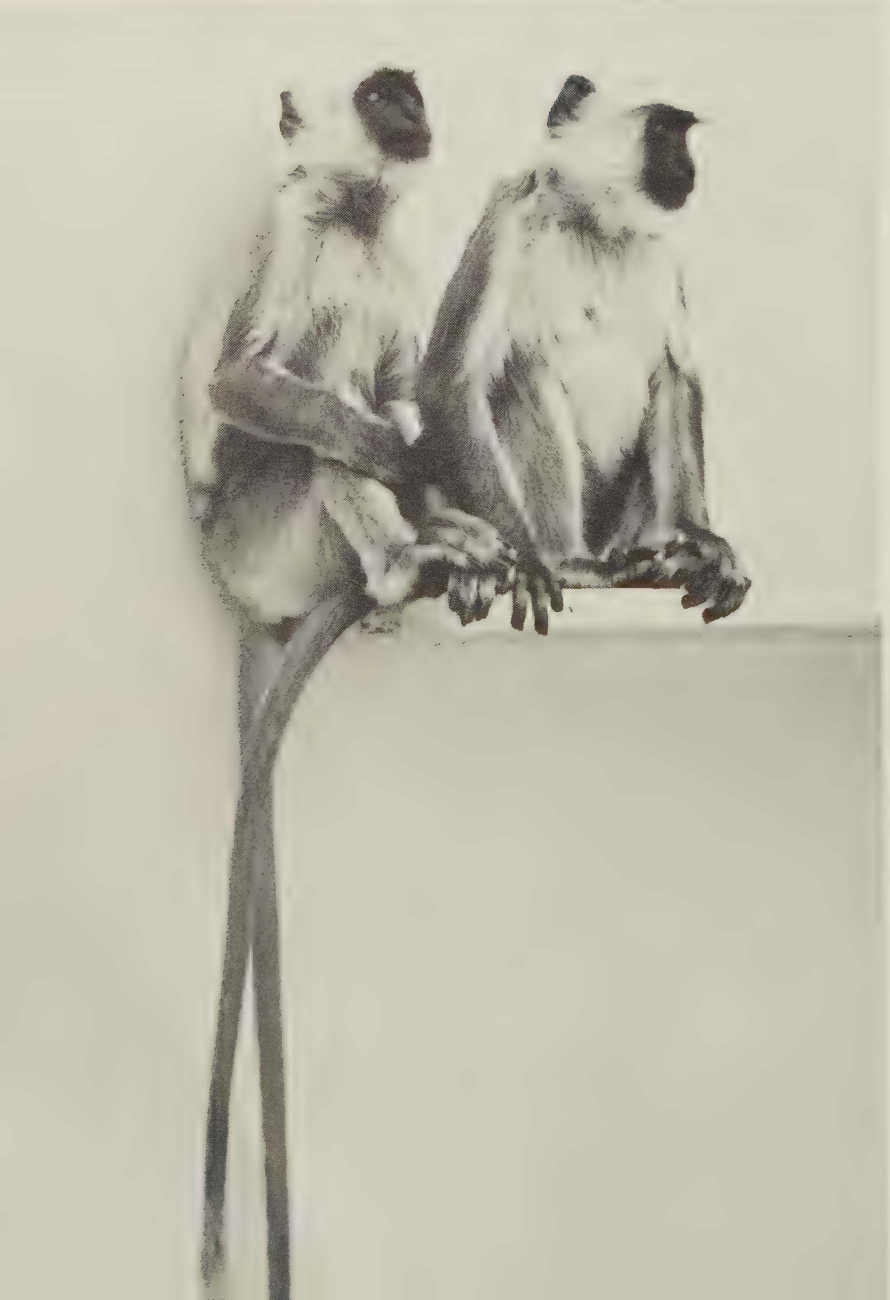

Recent additions to the collecti
are a pair of juvenile Commo
Langurs, *Presbytis entellus.*
These long-limbed, long-taile
black-faced monkeys are as
regularly seen about towns a
villages in India as they are i
the forest. Their unique
digestive system is markedly
different anatomically from
most monkeys, and therefore
it is difficult to keep this
species in captivity. Belongin
to the family of monkeys
commonly known as the "Lea
Eaters," the Common Langur
features an immense
sacculated, thin-walled stoma
in which the initial breakdow
of great quantities of vegetab
matter takes place. To
maintain these monkeys in th
peak of condition, their keepe
daily harvest the leaves, sho
stems and flowers of hibiscus
Cup-of-Gold and Eugenia (an
berries when produced). This
pampering has paid off with
the first births in captivity,
1926 and 1927, and a
longevity record for the spec
20 years and 5 months.

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SCUBA CENSUS OF FISH POPULATIONS

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INTRODUCTION

The principal methods of evaluating the size or density of fish populations include counts of entire populations, tagging, transects by aerial photograph or trawl, and indices of relative abundance (1). With the development of reliable scuba in recent years, at least two additional techniques are available. One, a method using swimming rates of fish and diver and number of encounters (2), is infrequently used; but another, the underwater transect method and its variations, is receiving considerable application.

Despite the appeal of counting and observing fishes directly in their own habitat, underwater methods developed to date have severe limitations. The discussion that follows is based principally on observations made of fishes of the kelp beds of Southern California (3) and Auke Bay, Alaska, and of several surveys of Traitors Cove Creek near Ketchikan, Alaska.

DESCRIPTION OF THE METHOD

The belt-transect method utilizes the movement of a census taken over an area of known or estimated dimensions. The organisms sought are counted and the data transformed to number per unit area. Various modifications have been used because of limitations of certain environments or unique advantages of others. Brock (4) and Bardach (5) set off the transect area with two parallel lines in their fish surveys of clear-water coral reef areas. In the surveys in Southern California a single line was used because of restricted underwater visibilities (ranging from 1-20 meters, with a usual range of 3-12 meters) and the broken, obstructed nature of the bottom. In surveys at Auke Bay no transect line was used, and a standardized rate of swimming gave an estimate of the distance covered. In the two-line method used by both Brock and Bardach, dimensions of the belt were automatically determined by the distance between lines and by the lengths of lines. In the single-line and no-line methods, fishes are counted within a predetermined, estimated distance from the observer. In surveys of regions where the habitat varies within the transect belt, a line marked off in uniform sections will aid in estimating proportions of habitats and habitat-fish associations. Twelve-meter sections were used in the Southern California studies.

Information is recorded in pencil on a white Formica slate, which takes ordinary pencil well under water. The pencil marks can be easily removed with household cleanser. A spherical compass for underwater navigation and a thermometer are attached to the upper edge of the slate. The complete apparatus is available commercially (6).

In most small freshwater streams scuba is not required for a fish census. Usually the stream is shallow and the water is clear enough for the observer to see necessary details on the bottom while he is floating at the surface. He should be equipped with faceplate, snorkel, and flippers, and an exposure suit if necessary. A slate is not required because the data can be given verbally to a recorder on shore. Broad streams may be surveyed by several divers swimming side by side, as described by Northcote and Wilkie (7). Rapids and swift water are difficult to investigate, and the greatest caution is advised in these situations. In deeper streams the marine method may be utilized unless currents and obstructions prevent it. The presence of strong currents may so complicate the safety procedures that underwater methods will not be feasible.

FACTORS AFFECTING ACCURACY

Scanning Efficiency. The density of demersal fishes that do not move about actively will nearly always be underestimated because most bottom fishes are cryptically colored and patterned to some degree. Also if the substrate is broken or overgrown with algae, some individuals will be hidden from the observer. Underestimation is likely if the transect belt is excessively wide because visual coverage, especially of the edges, will be incomplete. Care should be taken to choose a width that can be scrutinized fully, which will be contingent upon size and prominence of the species sought and water conditions. In clear Southern California waters, adult kelp bass (Paralabrax clathratus) were generally counted over transect widths of 10 meters, but counts of juveniles were restricted to widths of about one meter. Widths of approximately two meters, the diver's arm span, are currently in use in the Auke Bay investigations.

An unsolved problem exists in the case of schooling fishes whose school size-range exceeds the diver's vision. In this instance, other methods must be employed to obtain information on the number of fishes in the schools and density of the schools in the region. A superabundance of fishes within the transect area also is a potential source of error. If fishes are too numerous they will saturate the diver's perceptive capacities.

Diver scanning efficiency may decrease with depth. It is well known among experienced scuba divers that simple operations such as tying a knot or loosening a shackle can become very difficult at depth. Perception by the diver may be similarly affected, and some fish easily recognized and counted at 10 meters may be missed at a depth of 30 meters. Other factors entering into the problem of scanning efficiency at depth include low illumination and, in unpracticed personnel, anxiety.

Water clarity will have considerable effect on the choice of the transect method to be used. In water with considerable turbidity, visibility itself will limit the width of the transect belt. When divers are accustomed to turbid waters, unusually clear water may cause distorted distance estimates when single-line or no-line methods are used. In this instance a two-line method may be desirable.

Another problem concerns accurate counts of fishes that are about and above the diver. Often it is difficult to decide whether fishes are over the transect belt or not, particularly if they are a considerable distance overhead. In such instances it may be advisable to count fishes near the level of the diver only and to obtain counts on higher fishes in a second transect at the surface.

Fish Behavior. Usually, one of the first questions that arises when underwater transects are discussed is whether or not divers will frighten fish from the area before the fish can be seen and counted. Judging from observations in the relatively clear waters of Southern California, this is a minor problem, and negligible compared with its opposite -- attracting fish in from surrounding areas. However, the problem in Auke Bay, Alaska where underwater visibility is generally more restricted is quite different. During Spring and Summer 1962 no adult salmonids were encountered during surveys about the bay and in the region of Auke Creek, even during a period when sockeye salmon (*Oncorhynchus nerka*) were jumping in the vicinity of the creek mouth. Although this suggests that the fish were avoiding the divers, it is not proof, because transects were run below the approximately 12-meter-deep warm, turbid surface layer of the bay--typically at depths of 15 and 33 meters. Very possibly the adults were confined to this upper layer and could not be seen. Scuba observations on herring by other biologists at the Auke Bay Laboratory indicate that herring are not disturbed by divers *per se* but rather by the divers' sudden movements and the sound of bubbles from the scuba.

In Southern California, the reverse situation, that of attracting fish into the transect area, was a much more serious problem. If not compensated for, such behavior would cause serious overestimates of density. Some information on this problem was gained from transects repeated 17 times at the same site off LaJolla, Calif., during three months in Spring 1960. Distinctive variations were obtained for each of three common species.

Density of kelp bass remained relatively constant over the series, but in nearly all transects the number of fish counted by the diver while going out the line was approximately one-third greater than the number counted while returning. The cause of these differences could be observed during the transects--typically, fish moved in to investigate divers as they ran the "out" half of the transect, and many would follow along with the divers to the end of the line. When the divers returned on the line the cluster of fish usually was left behind and not counted, thus giving a lower count. The return count was averaged with the "out" count because not only did the combined values have a lower variance, but the artificially low counts of the return transect helped compensate for the artificially high values of the "out" count.

Repeat estimates for the California sheephead (*Pimelometapon pulchrum*) showed a marked change during the series. Early estimates had high values, but later estimates declined rapidly and stabilized at about one-third the original value. A suggested hypothesis to explain the changes is that sheephead were attracted to the divers by curiousity during the early part of the series and they lost interest as the divers became commonplace.

Blacksmith (*Chromis punctipinnis*), in contrast, showed drastically increasing counts through the series. The fish probably were aggregating during the series about rock outcrops in the region prior to their breeding season in June and July. Blacksmith pay little heed to divers.

These observations emphasize the need for considerable information on behavior and life history of fish species before reliable detailed studies of their populations can be made. If such information is not available, the biologist should make careful observations while the study is being conducted.

Size of Area Surveyed. Because of nitrogen buildup in the blood, with resultant danger of bends, diver time without decompression becomes progressively more limited as the depth of dive increases. Dives requiring decompression are time consuming, require considerable planning, and have an element of hazard not present in zero decompression dives. Because of these difficulties, they are usually not practical for routine fish census.

Wotking time under water is approximately halved with each 30-foot increase in depth (see Table 1).

Table 1. Time limits for dives not requiring decompression (8).

Depth (feet)	Time allowable
30	Unlimited
60	1 hour
90	30 minutes
120	15 minutes

With working depths greater than 30 feet, nearly all factors work progressively against obtaining an adequate sample size. Because the working time-depth relationship is nonlinear and visibility conditions are not always ideal, it is frequently impossible to survey more than a fraction of the terrain at a depth that can be surveyed in shallower water (see Fig. 1). Although water clarity may sometimes increase with depth, the amount of light available is always less, and objects can be difficult to see and recognize. The conditions of poor illumination lessen the width of transect belt that can be scanned efficiently. Decreased perceptive abilities of the diver at dpeth also call for a narrowing of the belt.

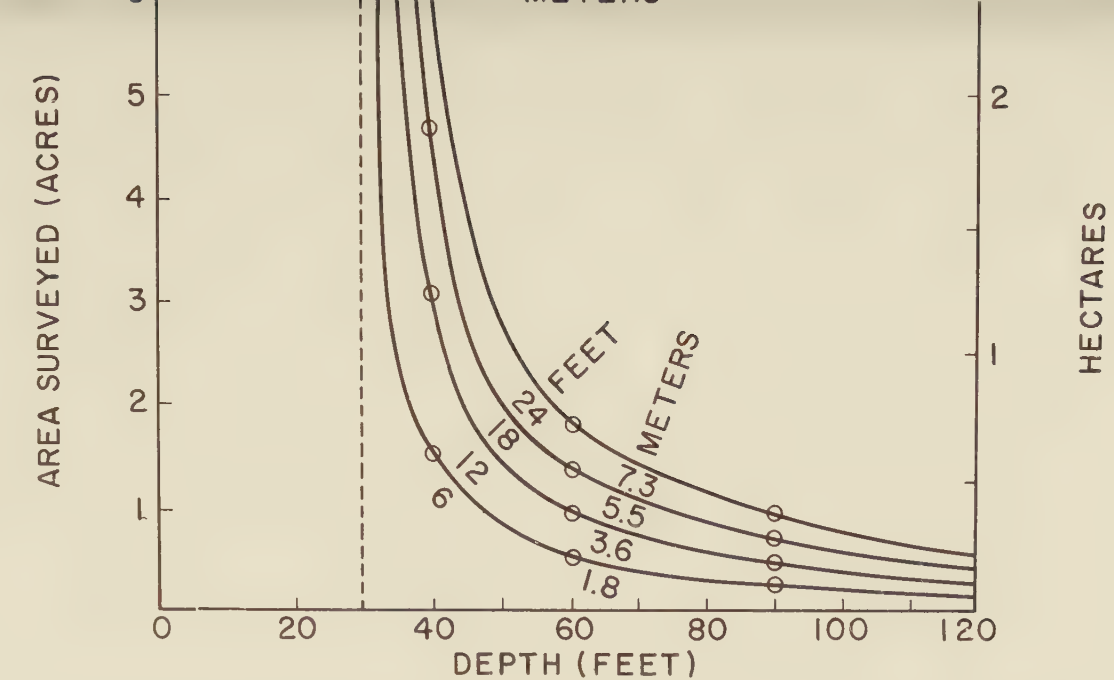

FIGURE 1.-- APPROXIMATE AREAS THAT CAN BE SURVEYED BY SCUBA WITH DIFFERENT TRANSECT BAND WIDTHS AND DEPTHS UNDER THE ZERO DECOMPRESSION SCHEDULE (U.S. NAVY, 1959). BASED ON A SWIMMING RATE OF 56.2 FEET (17 METERS) PER MINUTE.

Other Factors. Size estimation, difficult enough in the terrestrial environment, is further complicated in the aquatic one. Not only is the diver confronted with a variety of unusual backgrounds against which he must make his size estimates, but he must contend with a 25% magnification caused by his faceplate. Varying water turbidities will give him spurious distance cues. For these reasons, a minimum number of size classes should be used; for example, in the Southern California studies only three categories, juvenile, adult, and extra large adult were used. If an average size is needed to convert from counts to weight, some independent, more representative source should be utilized. In the California studies, size composition and length-weight regressions were obtained from the sport fishery and from collections made with seines, explosives, and rotenone.

DISCUSSION

With the described sources of error, it is not surprising that the underwater transect method is inexact. But, even with its recognized deficiencies, the method may be as accurate as or perhaps more accurate than the alternative methods listed in the introduction, except for the method of complete enumeration. It has the advantage that the biologist is in close touch with the animals he is studying and with their environment and is in a favorable position to detect shortcomings in his techniques and take appropriate corrective action. He is also in a position to gather important biological data on ecology, behavior, protective coloration, predator relationships, and feeding activities.

The area that can be satisfactorily covered on a transect decreases progressively with depth. Principal limiting factors are zero decompression time and illumination, both of which decrease exponentially. In a study applicable to the waters of Southeastern Alaska, Utterback (9) found only 0.44% of green light, the spectral region giving maximum penetration, at 30 meters that was present just below the surface. These factors in combination with probable lessened diver efficiency with depth preclude routine running of transects at depths much greater than 100 feet.

Experience indicates that some degree of clumping is the rule in demersal fish populations. An obvious cause is the presence of dissimilar habitat within the transect area, and it is surprisingly difficult to locate habitats that even appear homogeneous within the distance required for a transect. In most situations where the bottom appears to be reasonably uniform, the clumping of fishes may be assumed to be negligible unless clearly evident. In regions with obvious discontinuities in habitat, the proportions of different habitats should be recorded and the fish count isolated for the various habitats. A transect line divided into numbered, equal-sized sections will facilitate such treatment. If no transect line is used, the area censused should be selected to be as homogeneous as possible. Normally, the data obtained are suitable only for relatively crude analysis by nonparametric techniques, or by parametric techniques if they are properly transformed. The average coefficient of variation for the transect series at the locality investigated in Southern California was approximately 44% of the mean for kelp bass and California sheephead (untransformed data). In most fish surveys high levels of accuracy are not required, and the findings may be adequately stated in terms of levels of abundance such as absent, scarce, moderately abundant, and abundant, or equivalent numerical categories.

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p. 448

OCCURRENCE OF THE PACIFIC BONITO IN COASTAL ALASKAN WATERS. — Two unusual occurrences were noted for Pacific bonito, *Sarda chiliensis* (Cuvier), in Alaska during June 1963. Ten individuals were taken on 17 June near Luck Point (55°59′ N, 132°42′ W) on Clarence Strait, approximately 60 miles northwest of Ketchikan, and 1 was taken in early June near the mouth of the Copper River (60°16′ N, 145°32′ W), approximately 25 miles southwest of Cordova. Both collections were from commercial drift nets. One of the Clarence Strait specimens, 566 mm standard length, was forwarded to the Auke Bay Laboratory by Norman D. Johnston, Area Management Biologist, Alaska Department of Fish and Game, Petersburg. The specimen from the Copper River delta, 540 mm standard length, was forwarded by Rae Baxter, Assistant Area Management Biologist, Alaska Department of Fish and Game, Cordova. The specimens are numbered AB 63-107 and AB 63-141 in the Auke Bay Laboratory fish collection. The northernmost recorded occurrence for Pacific bonito is given by Clemens and Wilby (1961, Fishes of the Pacific Coast of Canada, p. 227) as the vicinity of Rivers Inlet, British Columbia (near the southern end of Calvert Island, Queen Charlotte Sound). The Clarence Strait and Copper River captures extend the range approximately 400 and 950 miles northward.

Data from Ketchikan indicate that the surface waters at nearby Clarence Strait may not have been warmer than normal. During the last half of May and all of June, the Ketchikan averages actually were lower than the 5-year average from 1958 to 1962. However, oceanic temperatures undoubtedly were warmer than normal during this period. Temperature charts furnished by the United States Bureau of Commercial Fisheries Laboratory, Point Loma Station, San Diego, give a range of 50 to 52 F for the ocean off Queen Charlotte Sound during the first half of May 1963, and 52 to 54 F during the last half. Although May averages for the northern Gulf of Alaska were not given, oceanic temperatures off southeastern Alaska were 2 to 4 F higher than the long-term average. Average temperatures for this region are given as 46 F for May by one source (U. S. Navy, 1956, Climatic Atlas of the World, Vol. II), and another (U. S. Department of Commerce, 1961, Climatological and Oceanographic Atlas for Mariners, Vol. II) places the 50.0 F isotherm at northern Vancouver Island during May. Oceanic temperatures for the southern Gulf of Alaska region were therefore definitely higher than normal during the period immediately preceding the captures and probably were higher in the northern Gulf of Alaska also.

During 1958, bluefin tuna occurred near Kodiak Island (Radovich 1961, *Calif. Dept. Fish Game, Fish Bull.* 112:1–62) and barracuda occurred in Prince William Sound (J. B. Kirkwood, personal communication). Although these records corresponded with unusually high temperatures in the Ketchikan region, no corresponding rise occurred previous to the bonito captures.—Jay C. Quast, *U. S. Bureau of Commercial Fisheries, Biological Laboratory, Auke Bay, Alaska.*

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The Importance of the Occurrence of Menhaden in the Coastal Waters and Estuaries of Peninsular Florida

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Abstract

Current information on the distribution and seasonal occurrence of juveniles and adults of three species of menhaden in Florida waters is summarized. Results suggest a resource potential of sufficient magnitude to support a commercial fishery, particularly off the southwest coast during the fall and winter.

INTRODUCTION

THIS IS THE THIRD REPORT on menhaden distribution presented to the Gulf and Caribbean Fisheries Institute. The two previous reports were given at the Twelfth (Reintjes, 1960) and Thirteenth (Reintjes and June, 1961) Annual Sessions. Additional information which has accumulated since then supports the belief that a sizeable population of yellowfin menhaden exists in Florida waters and that seasonal concentrations of Atlantic and gulf menhadens occur during the late fall, winter, and early spring. The purpose of this report is to summarize recent biological information that may help the fishing industry utilize these unexploited or underexploited resources.

Juveniles and adults of three species of menhaden are found in Florida. Although the ranges of the species overlap, the fishery in each locality is supported principally by a single species; near Fernandina Beach by Atlantic menhaden, *Brevoortia tyrannus;* in Indian River and on the southwest coast by yellowfin menhaden, *B. smithi;* and along the northwest coast by gulf menhaden, *B. patronus.*

Since the menhadens are a living resource, the problems associated with the dynamics of the fishery are essentially biological. The geographical distribution of both juveniles and adults provides a starting point for inquiry. Other biological considerations include (1) spawning, hatching, and early development; (2) age and size composition of the catch; (3) survival and growth of juveniles in the estuaries; and (4) behavior and migrations. These and other factors of menhaden biology may determine whether there is good or bad fishing and, ultimately, the success or failure of the industry.

DISTRIBUTION OF ADULTS IN FLORIDA

Very little is known of the distribution of adult menhaden in Florida outside of the reports of landings by the purse seine fisheries at Fernandina Beach and Apalachicola and the annual summaries by Rosen (1959, 1960) and Rosen and Robinson (1961, 1962, 1963). These authors showed an occasional landing of menhaden in nearly every coastal county of the State. No species identity was given except a statement that *B. tyrannus* occurred on the east coast and *B. patronus* on the west. None of the landings were identified as *B. smithi*.

Few reliable reports of adult menhaden in southern Florida are available. Suttkus (1958) reported *B. smithi* from Englewood and Gasparilla Sound on the west coast, and Tabb and Manning (1961) from Florida Bay, near Cape Sable. Biologists of the Bureau of Commercial Fisheries have collected large adults at Palm Beach, Miami, Marathon, Everglades City, and Naples. Last winter, within a few hours after menhaden-like schools were sighted from the air off Naples, menhaden were caught in the vicinity.

Atlantic menhaden

A purse seine fishery for Atlantic menhaden is conducted at Fernandina Beach from April to November. Fishing generally occurs in the vicinity of the reduction plant, but the fleet ranges from St. Augustine to Savannah, Georgia. The catch usually is composed of young, sexually immature fish, one to two years old. At the beginning and end of the season, a few larger, older fish occur in the landings, but never contribute substantially to the catch. These larger fish appear in gill net catches at Indian River in November and may constitute the older segment of a southern population. The hypothesis of a southern population of Atlantic menhaden is based on differences in size and age composition in the fishery, scale patterns, and fin ray, scute, and vertebral counts. Whether the larger fish appearing off central Florida are the remnants of a short-lived population or a portion of an exploitable stock has not yet been determined.

Yellowfin menhaden

Yellowfin menhaden occur throughout the year in the coastal waters of Florida. Although the extreme range for the species is from North Carolina to the Mississippi Delta, these fish are reportedly abundant only in Florida. A gill net fishery is conducted in Indian River, from New Smyrna to St. Lucie Inlets on the Atlantic coast, and from Suwannee to Sarasota on the Gulf of Mexico. Because of mesh selectivity, the gill nets catch only large, adult fish, approximately three years old. Combined landings have not exceeded 500,000 pounds annually. The catch is sold fresh or frozen for crab bait.

In other localities, yellowfin menhaden are caught incidentally in the seine and gill net fisheries for Spanish mackerel, pompano, and mullet. There is no market for them, however, and they usually are discarded at sea. Small quantities, probably less than 10,000 pounds, annually, are landed at Palm Beach, Miami, Everglades, Naples, Fort Myers, and Punta Gorda.

Another species, fine-scale menhaden, *B. gunteri*, occurs in the Gulf of Mexico but has not been reported from Florida. Yellowfin menhaden from Florida and fine-scale menhaden from Texas are distinguishable from each other by differences in body shape and vertebral and scute counts, but specimens occurring together in Mississippi are not so easily separated. There is some doubt these are two separate species as reported. They may be different populations of a single species.

Gulf menhaden

Until 1962, a purse seine fishery for gulf menhaden was located at Apalachicola. The fleet ranged along the coast from Panama City to Cedar Keys, with occasional catches, in some years, from the vicinity of St. Petersburg. Age and size distributions of gulf menhaden taken by purse seines are strikingly different from those of Atlantic menhaden. Present knowledge of the gulf menhaden is meager, but there apparently is total mortality by age three. This mortality is essentially the same as in an Atlantic menhaden fishery limited to Chesapeake Bay. Whether the high mortality of gulf menhaden is the result of migration, as in Chesapeake Bay, or death, is unknown. If it is migration, somewhere there is an adult stock which might be exploited. If the stock were discovered and exploited by foreign fisheries, the domestic resource could be in jeopardy. On the other hand, if gulf menhaden die at age three, the fishery is depending on the spawning potential of a single year class for each year's brood stock. In either event, it is important to the industry that the fate of these older fish be learned.

According to Roithmayr and Waller (1963), gulf menhaden occurred during all months of the year in catches of the U.S. Bureau of Commercial Fisheries exploratory vessel OREGON and in samples from the otter trawl landings at Pascagoula, Miss. These authors suggested that the gulf menhaden wintering area may be in the north central Gulf of Mexico, not far from the Mississippi Delta. Their conclusion may be correct, although we have found Atlantic menhaden in otter trawl catches off New York and New Jersey throughout the winter, and we are reasonably sure the wintering area for most of the population is south of Cape Hatteras. This comparison of findings for the Atlantic menhaden and gulf menhaden may not be valid, however, for the migratory behavior in one species is no assurance of the same behavior in another.

Gulf menhaden, larger than those usually occurring in the purse seine fishery, were taken off Naples during the winter. This locality marks the southern extremity of the range for adults. As long as the existence of any significant numbers of the larger gulf menhaden is unknown, these occasional and seemingly unimportant occurrences may be a significant discovery.

DISTRIBUTION OF JUVENILES IN FLORIDA

All of the major estuaries of Florida are nursery grounds for juvenile menhadens. Although the ranges of the three species overlap, a single species usually dominates in each geographical area. Atlantic menhaden is the dominant species in estuaries from Cape Kennedy northward, yellowfin menhaden from Cape Kennedy to Tampa Bay, and gulf menhaden from Tampa Bay north and westward.

Atlantic menhaden

Atlantic menhaden occur abundantly in estuaries from St. Augustine northward, but diminish in numbers to the southward. A few specimens have been taken in Indian River and only two specimens occurred in collections from St. Lucie River, the most southern occurrence of the species. In northern Florida, the St. Johns and St. Marys River systems are important menhaden nursery areas.

Yellowfin menhaden

Juvenile yellowfin menhaden occur in most estuaries from Cape Kennedy to Tampa Bay. Although we have no specimens from Lake Worth or Biscayne Bay, fishermen report that juveniles are very numerous in some years. Collections of spawning yellowfin menhaden landed at Palm Beach and Miami during 1960 support these reports. Tabb and Manning (1961) obtained juveniles from Coot Bay Pond near Cape Sable in 1957 and additional specimens were obtained at the same place in 1961 and 1962. On the west coast, juveniles occur in all principal estuaries northward to and including Tampa Bay.

Gulf menhaden

Juvenile gulf menhaden occur commonly in all estuaries from Tampa Bay northward, but southward their numbers decrease. At Cape Sable, for example, only two specimens of gulf menhaden occurred among several hundred yellowfin menhaden. Although juveniles are distributed along the west coast, important contributions to the gulf menhaden resource appear to be limited to the estuaries from Apalachee Bay westward.

SUMMARY AND CONCLUSIONS

Adult menhadens occur seasonally in the coastal waters of Florida, but the absence of a commercial fishery south of Fernandina Beach makes a quantitative estimate of their abundance nearly impossible. The incidental commercial landings and reports of adults, plus the presence of juveniles in all of the estuaries, indicate that the menhadens are more abundant than is commonly believed.

An understanding of the seasonal and spatial distribution of each species present in Florida waters may help solve some of the most pressing problems, namely: (1) the fishery potential of yellowfin menhaden, (2) the contribution of Florida estuarine nurseries to the fishable population, (3) the location or existence of older and larger gulf menhaden.

At a time when the menhaden resources are showing signs of instability or weakening, and when other nations are showing interest in the fisheries of the south Atlantic and Gulf States, the answers to these problems are of vital importance to the menhaden industry of the United States. Current studies of the Atlantic menhaden and recently initiated studies of the gulf menhaden are designed to answer some of these problems.

ACKNOWLEDGMENTS

I wish to acknowledge the collections furnished by Dr. Robert A. Harrington, Jr., Entomological Laboratory, Florida State Board of Health, Vero Beach; and Dr. Victor G. Springer, formerly with the Marine Laboratory, Florida State Board of Conservation, St. Petersburg, and now at the U.S. National Museum.

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THE HAWAIIAN MONK SEAL

by

Dale W. Rice

from

NATURAL HISTORY 73(2): 48-55

February 1964

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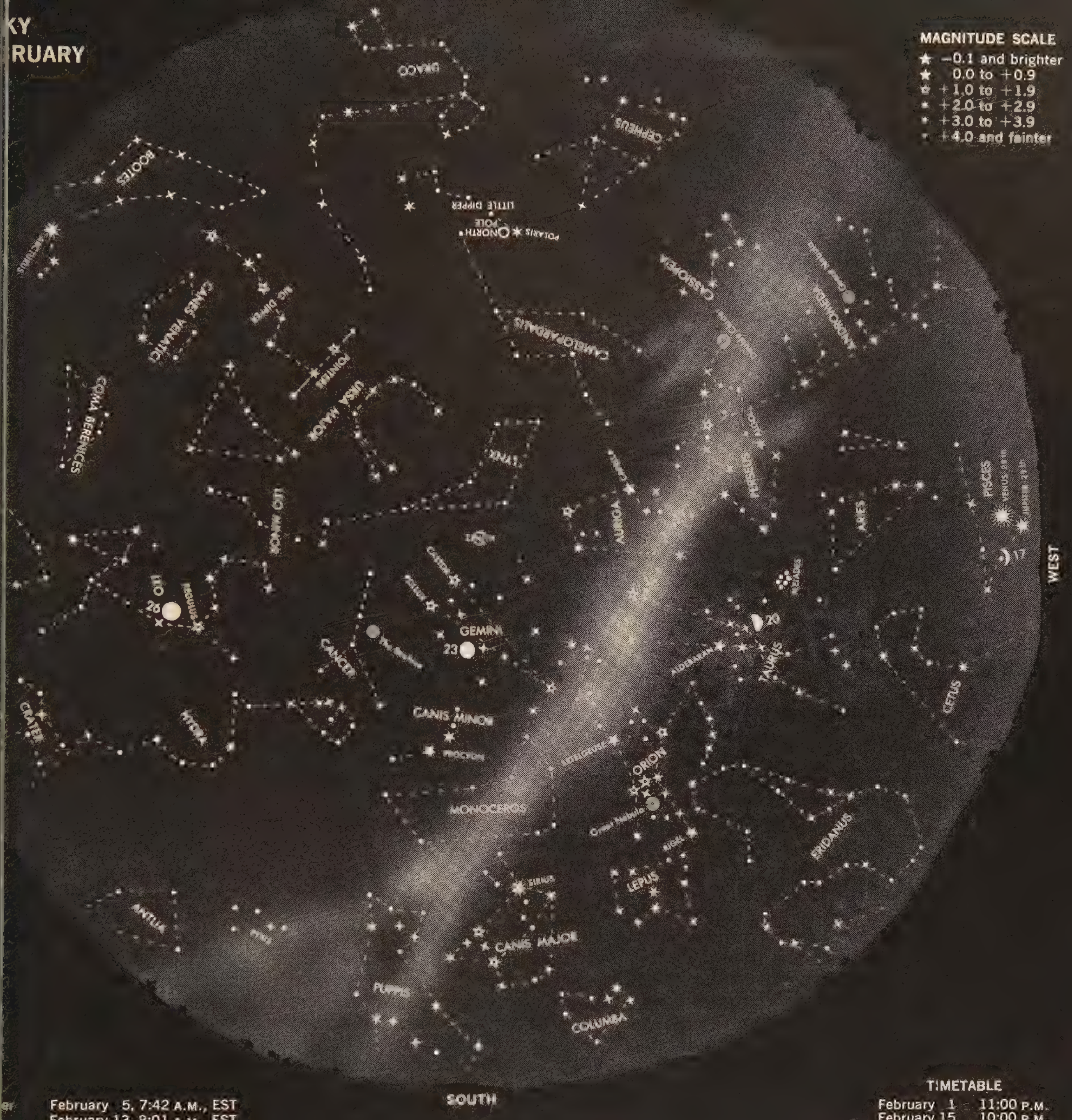
RUARY



er February 5, 7:42 A.M., EST
February 13, 8:01 A.M., EST
er February 20, 8:24 A.M., EST
February 27, 7:39 A.M., EST

TIMETABLE

February 1	11:00 P.M.
February 15	10:00 P.M.
February 29	9:00 P.M.

(Local Standard Time)

ary 15: Saturn and the sun are in conjunction, or n line as seen from earth. Saturn leaves the evening becomes a morning star, but it will not be readily until after mid-March.

ary 16: Mars and the sun are in conjunction. Mars the morning sky, but it will not be seen easily as a star until late spring of this year.

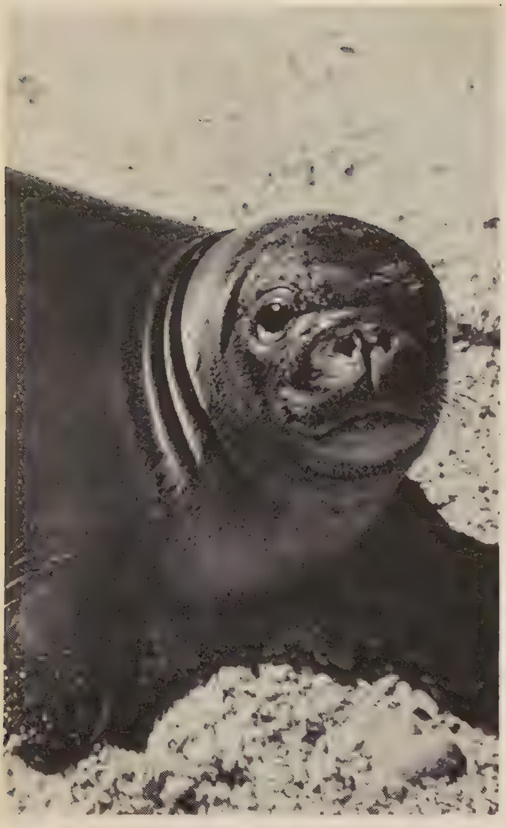
ary 15, 16, 17: Jupiter, Venus, and the moon are ng to watch on these evenings. On the evening of n, the crescent moon appears lower than Venus, and is higher than Venus. Venus and the moon are in tion about 8:00 A.M., EST, on the 16th, and by the of the 16th, the moon appears between Venus and Then, about 4:00 A.M., EST, on the 17th, Jupiter and on are in conjunction. In the evening sky of that date on appears above Jupiter.

ary 28: Venus and Jupiter are in conjunction about M., EST, Venus passing within two degrees of Jupiter. evening of the 27th, the two brilliant planets are quite nd Venus, brighter of the two, is slightly below and to the right of Jupiter. By dark on the evening of the 28th, Venus has already passed Jupiter, but the two planets are still quite close to each other. However, this time Venus is slightly above Jupiter.

Mercury may be seen low in the east during the early dawn for several days during the first week of February, but only with difficulty. Although bright (magnitude zero), it rises only an hour and a half before the sun on February 1, and is soon lost in the brightening sky. Later in the month, it dims and moves closer to the sun.

Saturn and Mars, although they are morning stars, are much too close to the sun to be seen.

Jupiter and Venus appear each night during the month of February in the twilight sky to the west, shortly after sundown, long before any star can be seen. Venus, the brighter of the two, appears first, then Jupiter—above and to the left of Venus for most of the month. Jupiter, although receding from earth and growing fainter, is brighter (magnitude −1.8) than any star. During the month Venus brightens from magnitude −3.5 to −3.7, because it is getting closer to earth.



EXTREME FATNESS is characteristic of the newly weaned monk seal pup.

The Hawaiian Monk Sea

Rare mammal survives in Leeward Island

By DALE W. RICE

IN THE MIDDLE of the North Pacific Ocean, the Leeward chain of islands extends like the tail of a comet for twelve hundred miles northwest of the main Hawaiian Islands. The islets nearest to Hawaii are jagged chunks of volcanic rock, the remnants of once higher islands. But at the far end of the chain, the volcanic peaks long ago sank beneath the sea; these islands have kept their heads above water only because their crowns of reef c have grown upward to compensat the sinking. All summer long, an less succession of heavy ocean s running before the steady north trade winds, break over the fring reefs into sheets of foam, slide ove blue-green shallows, and hurl t selves onto the glaring white sand beaches. Those lonely bea and shallow lagoons are the hom one of the world's rarest mamm the Hawaiian monk seal.

k seals are the only tropical and
ical members of a predomi-
cold-water family—the Pho-
or earless seals, of which there
ee species. The Mediterranean
seal *(Monachus monachus)*,
own to the ancient Greeks, now
s only in a few scattered col-
n the Mediterranean and Black
ladeira and the Canary Islands,
long the northwest coast of
. Columbus discovered the
ean monk seal *(Monachus trop-*
which was formerly abundant
Bahamas, the Florida Keys, the
r Antilles, and along the east
f Mexico. It probably has been
inated. The Hawaiian species
chus schauinslandi) is endemic
Leeward Islands end of the
an Islands chain.

did the monk seals come to
nis relict, pantropical distribu-
Probably we shall never know
ails of their history, but after
a detailed study of their skull
s, and taking into account what
ologists have learned of the fossil history of the phocid seals, I think the following hypothesis is the most plausible: the earliest phocids were descended from otter-like carnivores that lived in the fresh-water lakes of Asia during the Miocene Epoch—some twenty million years ago. As the extensive lakes slowly disappeared, the ancestral seals moved into the coastal seas. Some went north, into the Arctic Ocean; their descendants are the modern northern seals, such as the harbor and ringed seals. Others moved south to the vast Tethys Sea, precursor of the Mediterranean, which bordered the southern edge of Eurasia; from them the monk seals (and also the Antarctic seals and elephant seals) are descended.

Of all the earless seals, the monk seals have probably changed the least since Miocene times—they have not acquired the specializations that characterize the other branches of the family that invaded the cold polar regions. One species of monk seal has remained in the Mediterranean. From this birthplace, they pushed westward to the Caribbean, and eastward across Polynesia to the Hawaiian Islands. Since the extinction long ago of the intervening populations, the three groups of monk seals developed the distinctive traits that entitle them to recognition as separate species.

For many millenniums, the Hawaiian monk seals lived undisturbed on their remote islands. Apparently even the seafaring Polynesians never reached the western atolls of the Leeward chain, a fact that may account for the seals' survival here—and nowhere else—in the Pacific. In the early 1800's the intrepid whalers, sealers, feather-hunters, and guano-diggers, who in a few decades filled in the blank spaces on half the globe, discovered the Hawaiian monk seals' retreat. To them, the monk seal was only another source of oil and hides. Their slaughter of the animals on the Leeward Islands was characteristically thorough—almost complete, in

Churning water in her wake, a female repulses advances of a courting male.

fact, by the year 1896, when Dr. H. H. Schauinsland, the German scientist after whom the species was named, visited Laysan Island. During his stay he saw no seals, but Max Schlemmer, who operated a guano works on the island, gave him the skull of a seal, one of only seven that had been seen during fifteen years. The Hawaiian monk seal thus barely escaped being exterminated without its existence ever being known to the scientific world.

With the coming of the twentieth century, petroleum reduced the need for whale and seal oil. The age of the sea hunters had ended. The few surviving monk seals and their sea bird neighbors once again were left to themselves. The Commercial Pacific Cable Company, Pan American Airways, and finally the U.S. Navy occupied Midway Islands, but they were too busy to bother, or even to notice, the seals. The other five atolls on which the seals lived remained uninhabited and very seldom visited.

When Karl Kenyon (Natural History, November, 1963) and I were assigned to Midway Islands in late 1956 to study the albatrosses, or "gooney birds," which nest by the thousands on the Leeward Islands, we were also determined to learn as much as possible about the monk seal—how many there were, and how they lived in an environment so different from that of their cold-water relatives.

The first seal I met was sleeping in the shade of the "scavvy" thickets *(Scaevola frutescens)* that rimmed the upper edge of the beach. I did not see him until he raised his head to look at me, and then lowered it and shut his eyes. A moment later he raised it again and took another look. With mouth closed he voiced a pec "bgg-bgg-bgg-bgg-bgg," like w bubbling from an upside-down He lumbered into the water, dived, surfaced a few yards off the bea from whence he continued to watch a while before swimming off to fin place where he could resume his without being interrupted. This inn tameness, we found, is characteri of monk seals—it probably comes fr having lived so long on islands wh there are no land predators to att them. Even seals on Midway, wh have contended with man for only a century, are no less tame than th on other, rarely visited islands. W I went spear-fishing, I sometimes them watching me under water.

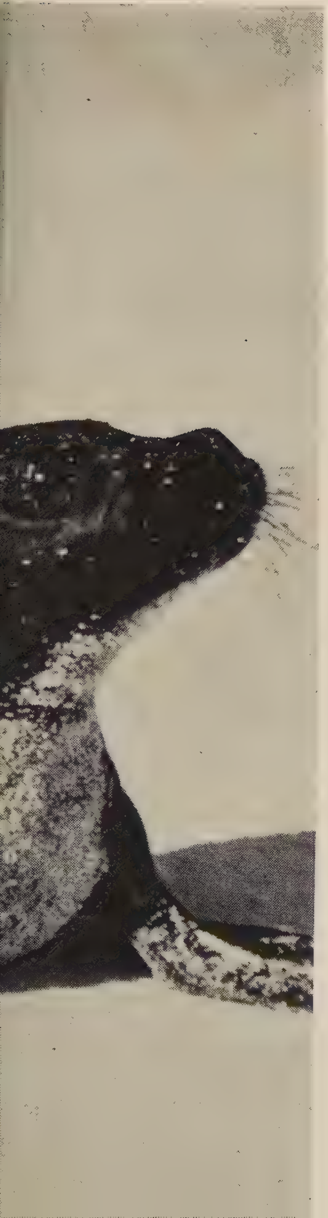
These behavioral traits were imp tant clues to the relationships of monk seal. When I later imitated bubbling voice for a biologist fr

aland, he said it sounded just
leopard seal *(Hydrurga lep-*
and other Southern Hemis-
pecies, which share the innate
s. I have since heard northern
seals *(Mirounga angustiros-*
er a similar sound.
ring advanced, and cool, windy
ecame less frequent, the first
ere born. We found that when
ales were ready to give birth
pups they tended to congregate
in beaches and islets that were
d from wave action, either by
antial barrier reef, or because
re on the lee side of the island.
ere also high enough so that
could crawl out of reach of
pring tides. Although mother
lerated each other's presence,
gorously repelled all other seals,
larly courting males that at-
d to approach them. Unlike
other species, such as the gray seal *(Halichoerus grypus)* and the elephant seal, there was no harem formation or other social ties between individual monk seals.

Most of the pups at Midway were born on the small islets that could be visited only by special trips in a small boat. We placed numbered metal tags on the flippers of all these pups, but the weather and our work with the gooney birds prevented us from examining them at regular intervals. Finally one evening in late March a message arrived from Chief Green of the Communications Unit on Eastern Island (a restricted area) — two monk seals had just given birth to pups. This would enable us to make the regular detailed observations necessary to obtain sound biological data. The next morning we caught the early boat to Eastern Island. Chief Green led us to the two mother seals, who were lying on the beach beside their tiny, jet-black pups. The mothers were enormously fat. An average non-pregnant female, 7 feet 6 inches long, will weigh about 450 pounds, but a pregnant female may weigh 550 to 600 pounds. (Males are smaller; they average about 7 feet in length and 375 pounds in weight.) We were soon to learn the reason for the mother seals' obesity.

The mother seals showed no fear of us. They were not disturbed by our presence until we came too close; then they threatened us with open mouth and loud bellows. Karl Kenyon had to divert the mothers' attention while I leaped in and kidnapped their pups. We had to weigh, measure, and tag each pup quickly, before its angry mother could get to us. Reunited with their pups, the mothers sprawled on their sides, seemingly oblivious to our presence, and the pups began to nurse. We were surprised to find that the mother monk seal has two pairs of functional teats. All the other species

BLACK PELAGE of monk seal pups may protect them from tropical sun. They nurse frequently from their mothers' four functional teats and grow rapidly.

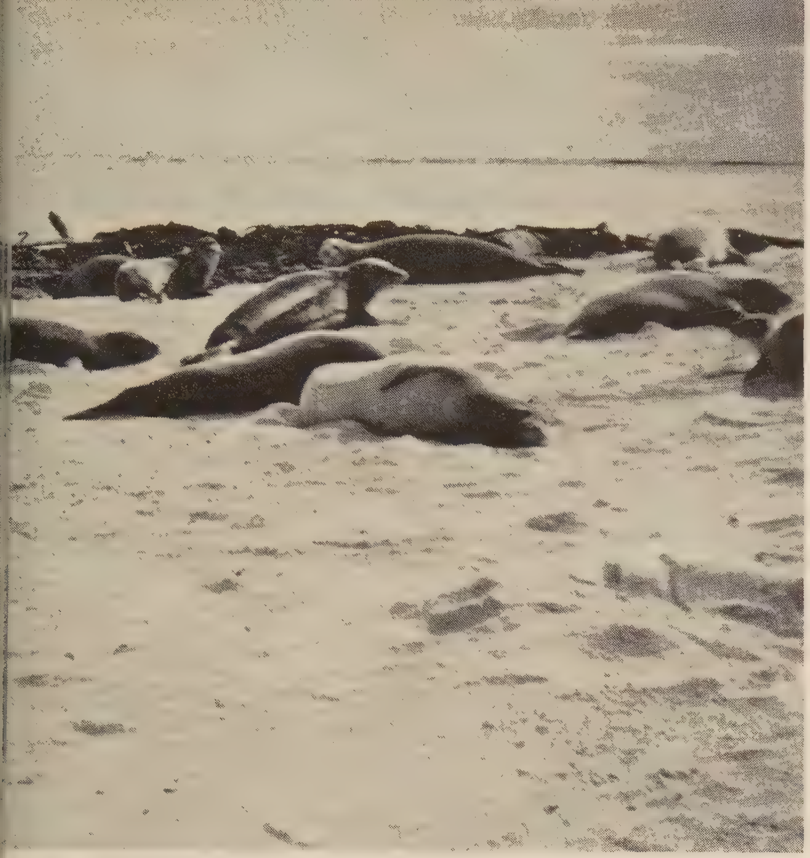


DURING first five weeks of life, the pup remains with its mother constantly.

Numbered metal tags were placed on flippers of seals, which were measured and weighed at regular intervals.

Laysan and Lisianski Islands and Pearl and Hermes Reef are so remote that seals are undisturbed, *right.*

Females gather in sheltered areas before parturition, and will attack courting males when pups are small.



rless seals, except the bearded
(*Erignathus barbatus*) of the
, have only one pair. The pos-
n of two pairs was probably the
ion in the ancestral phocids.

E closely followed the develop-
ment of these two young. At
eighteen days of age, they began
d their velvety-black birth coat,
is so different from the woolly,
or pale-gray birth coats of most
vater seals (NATURAL HISTORY,
ı, 1962). Elephant seals are the
other phocids whose pups are
with black pelage. This dark hair
bly protects the species from the
e sunlight of their near-tropical
The new pelage was short and
, and was a dark, silvery-gray
, shading to white below, like
f the adults. By the time they
four weeks old, their teeth had
to appear. This was their per-
t set of teeth, for unlike most
ıals, the milk teeth of earless
are resorbed before birth.
birth the pups weighed less than
pounds, and were extremely
. With frequent nursing periods,
ow began to fill out. By the time
vere four days old, they would
for brief periods in the shallow
At first they swam weakly, and
sometimes rest their forequarters on their mothers' backs. They soon became strong swimmers and spent more time in the water. The mothers' protective reactions were so strong that, even if they were swimming more than fifty yards offshore with their pups, they would come ashore to threaten us if we appeared on the beach. Since their young always followed them ashore, we could catch the pups for periodic weighings.

At Kure Atoll, while trying to distract a mother seal so we could examine her pup, I got too close. She grabbed my field notebook from my hands, shook it in her teeth, and flung it down into the sand!

Since the mothers remained with their pups continuously, they had no opportunity to feed, and the frequent nursing of the pups was a heavy drain on their blubber stores. We estimated one mother seal's weight at about 575 pounds when her pup was born. The weights of the pups increased at an unbelievable rate. One of them doubled his birth weight in fifteen days, tripled it in eleven more. By the time he was thirty-five days old, he weighed over 140 pounds, or four times his birth weight. His length had increased from 38 to 48 inches. He was so plump he could hardly move! His mother was now a gaunt creature, for she had lost almost two hundred pounds. For each two pounds the mother lost, her pup gained one. Eventually, when she no longer could nurse her pup she quietly slipped away and disappeared while he lay sleeping.

The other pup, whom we named "Little Herman," was deserted by his mother when he was but twenty days old, and weighed only 82 pounds. His mother was not as fat as the mother mentioned above, and evidently was unable to nurse him any longer.

The months ahead were critical ones for the pups, for they had to learn to catch their own food. Their blubber stores helped to tide them through this period. At first they showed little inclination to leave their birthplace. We continued to weigh them at regular intervals. Sometimes we had to wade into hip-deep water to catch them; then we dragged them ashore, amid tremendous splashing.

Their weight steadily fell as they used up their blubber stores, but they were slowly learning the ways of adult seals. We sometimes saw them playing. They would dive, pick up a rock or some other object, bring it to the surface, drop it, and dive again. In this way they probably discovered what things were good to eat. They also began to wander farther from home. When the hot, still days of July arrived, we could no longer find them in their old haunts. They had probably moved to the outer reef, where many of the adults haul out during the summer months.

We next saw the pups when the windy days of autumn drove the seals back to the protected islets and sand bars near the main islands. Both their appearance and behavior were greatly changed. They weighed only about a hundred pounds, but they were longer —4 feet 3 inches, on the average—and had the streamlined shape of adult seals. No longer would they docilely let us weigh and measure them. It was a two-man job to wrap them up in a net to immobilize them and keep their strong jaws out of mischief.

Although most of the other tagged pups had survived, we never found Little Herman again. Apparently his scant blubber supply failed to last until he learned to find his own food.

This is probably how the food supply regulates the number of monk seals. When the seal population is high, supplies of readily available food would be somewhat depleted; the fe-

males would be unable to put on much blubber, and their pups' chances for survival would be correspondingly reduced. Our observations suggest that female monk seals do not give birth two years in succession. Only the females who do not have pups will accept the advances of the courting males. The physiological strain of rearing a pup probably prevents females from becoming pregnant again until they have regained their store of blubber during at least one entire year of uninterrupted feeding.

THE only sure way to determine an animal's food habits is to examine its stomach. Because the monk seal is one of the world's rarest mammals, we did not wish to collect many of them. In fact, we killed only two—both males. We also found the spewed stomach contents of two others. This revealed that they feed principally on octopuses *(Octopus* sp.*)* and moray eels *(Gymnothorax* sp.; *Echidna* sp.*)*, which live in the crannies among the coral formations, and on conger eels *(Ariosoma* sp.*)*, which burrow in the sandy bottoms of the shallow lagoons. They also take a few bottom fishes and reef fishes, such as flatfish, puffers, and goatfish. Octopuses and eels usually venture out of their hiding places only at night; this suggested that the monk seals feed mostly nocturnally. I had a chance to confirm this during a visit to Laysan Island, where we camped just above the beach. During the middle of the day, we sometimes counted more than three hundred monk seals basking in the sun on the beaches. But on several brightly moonlit nights I walked the beaches and found not a single seal, except mothers with pups.

In the summer, after the breeding season was over, we discovered another surprising fact about the monk seals. They began to molt their old pelage, now stained a yellowish brown. Instead of shedding each hair individually, like most mammals, they shed the epidermis in large, ragged patches. Shedding the epidermis in this manner is characteristic of reptiles, but of only one other mammal—the elephant seal. This, along with other features, such as the black coat of the pup, suggests that elephant seals and monk seals are very closely related.

At Midway, the regular boat run between Sand and Eastern Islands passed near the islets and sand bars that were the seals' favorite hauling grounds. We counted the animals on every trip—sometimes there were more than sixty. Low-altitude photoreconnaissance flights over the albatross colonies also gave us an excellent opportunity to make periodic counts of the monk seals on Kure Atoll, Pearl and Hermes Reef, Lisianski Island, Laysan Island, and French Frigate Shoal. We also visited some of these islands by ship. The total population in the winter of 1957/58 was about twelve hundred—a gratifying increase from earlier years, yet a vulnerably low number for any animal species.

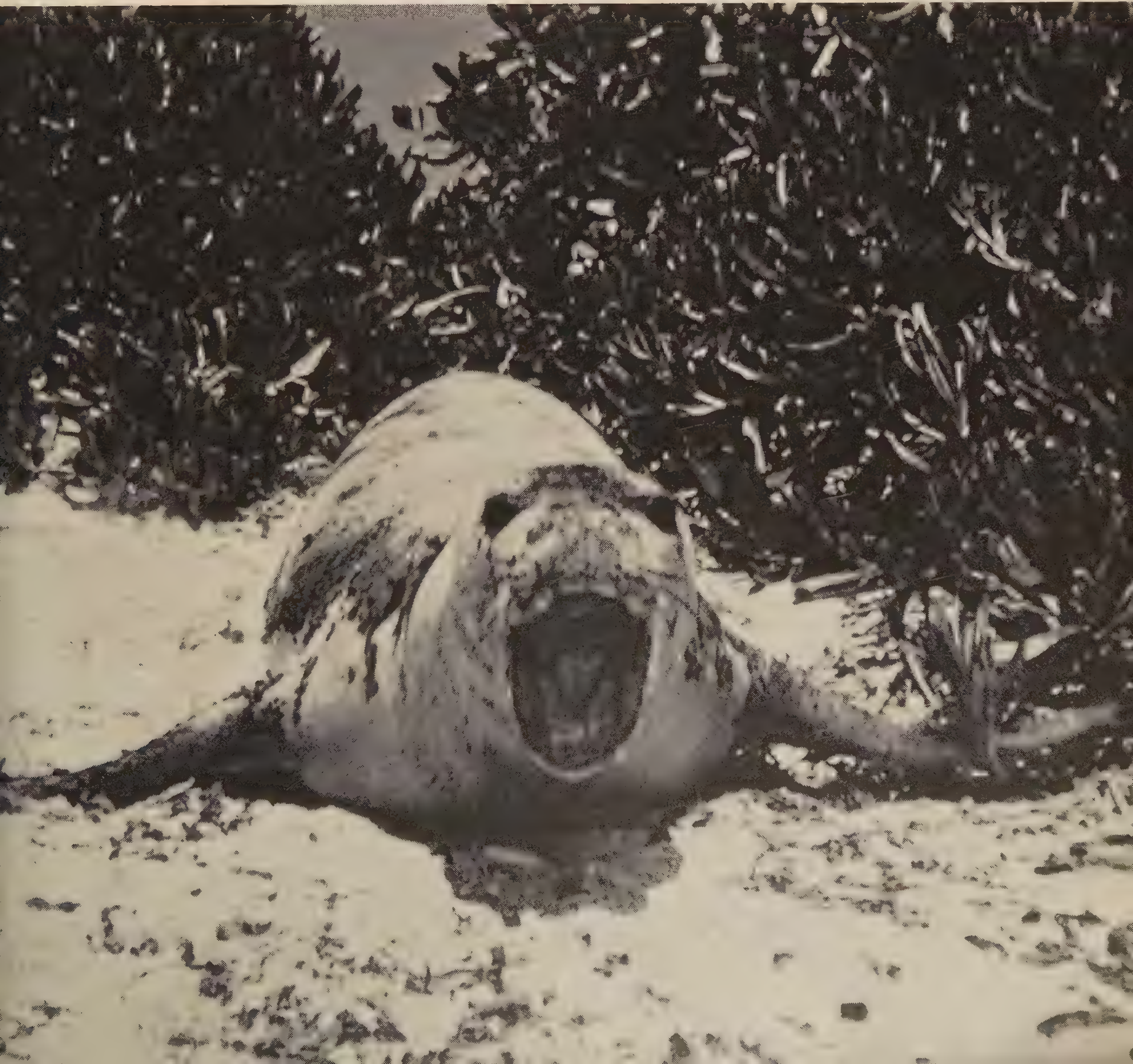
The reproductive rate of the monk seal is very low, even for a large marine mammal. Females apparently do not breed until they are at least three years old and then, as has been said, they probably do not give birth more often than once every two years. The bearded seal is the only other phocid known to have such a breeding cycle. In the spring of 1958, about one hundred seventy pups were born, a birth rate of only 14 per cent.

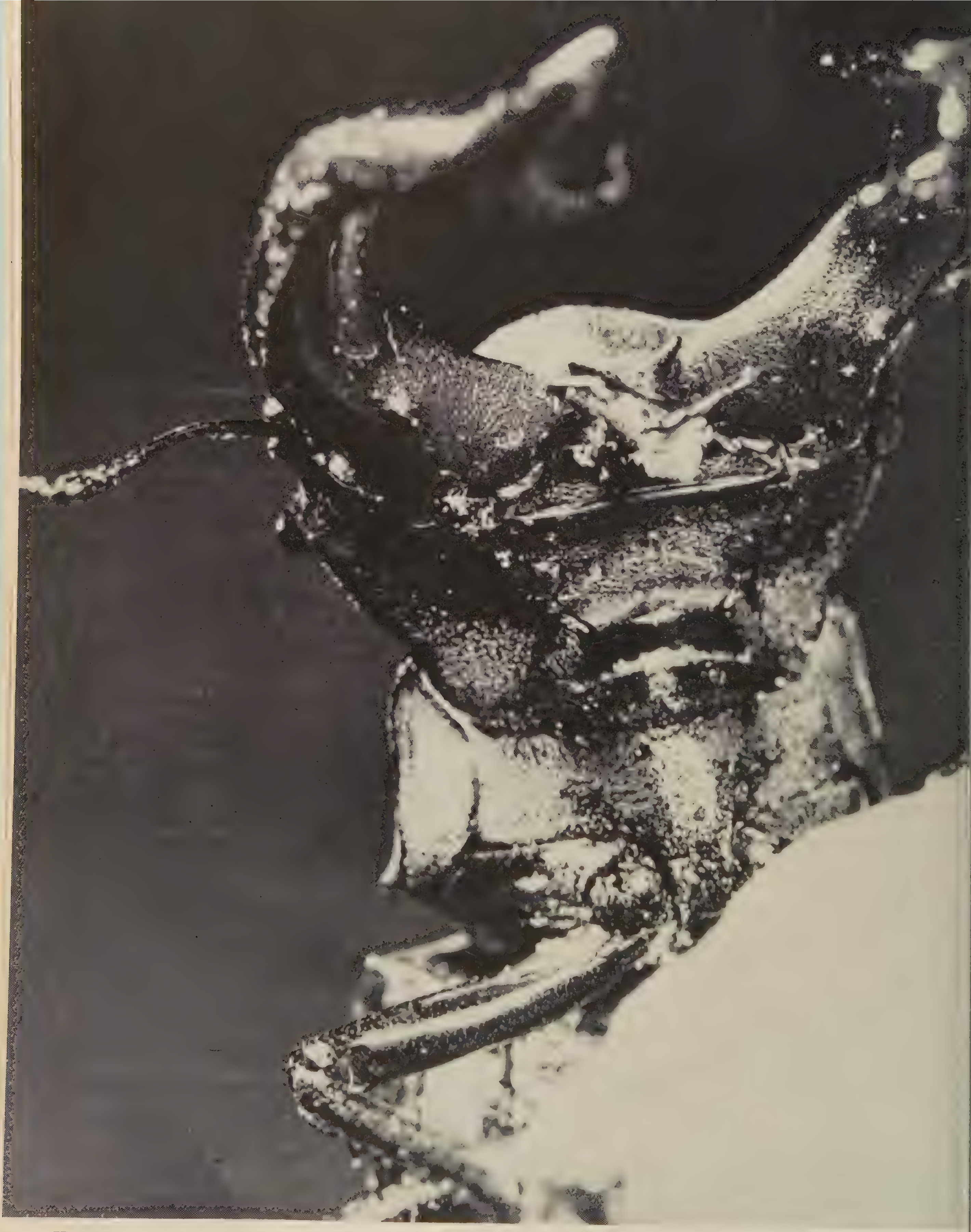
I saw one seal with a hind flipper missing, and others carried large scars on their sides, possibly the results of shark attacks. We encountered many sharks, including 12-foot tiger sharks *(Galeocerdo cuvieri)*, in the shallow lagoons, but they seemed to pay no attention to the seals, not even to pups. The seals have no other predators to fear in the shallow lagoons. Our counts indicated that the annual death rate must be very low—about 3 per cent. Like other marine mammals, they tend to live long. Annular layers in the cementum layer of the canine tooth of
one adult male that we collected i
cated that he was twenty years old
present the seals seem to be increa
their numbers by approximately
per cent each year.

EXCEPT for Midway, which is
site of the large U.S. Naval
tion, all of the islands on which
monk seals live are part of the Leew
Islands Bird Reservation, admi
tered by the Fish and Wildlife Serv
U.S. Department of the Interior.
would seem to insure their surv
However, in recent years disturba
by man has become an increa
threat. The U.S. Coast Guard ha
station on Tern Island in Fre
Frigate Shoal, and has recently ta
over Kure Atoll. Seals still occ
Midway, in spite of its large hu
population, but in '57 and '58, at
seven of the eighteen pups born at
way failed to survive until wean
On the other islands, we found
one dead pup. The causes of the de
at Midway apparently were the i
rect results of human activity—det
tion of explosives in the ship char
and perhaps persistent disturban
mothers with pups by photograp
beachcombers, boating parties,
dogs. But on Laysan and Lisia
Islands, and among the vast expa
of Pearl and Hermes Reef, the m
seals still spend the quiet, dark ni
fishing in the warm, coral-studde
goons, and bask undisturbed under
glaring tropical sun, as they have c
for uncounted generations. Let us h
that they may continue to thrive
increase for many more.

Tameness of monk seals is remarkable. This may be a result of living so long on islands that are without land predators.

Male, in threat posture, is molting, when, unlike most mammals, the seals shed epidermis itself in large and ragged patches.





HUGE UPPER JAWS of a European stag beetle lend insect bizarre appearance. If the pincers are larger than normal, they will hamper beetle in fighting.

The ASB BULLETIN

ume 11, Number 4

October, 1964

Ervin Alan Studios

Riverview High School Marine Laboratory—See pages 78 and 87-89

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Riverview High School Marine Laboratory, Sarasota, Florida
(See article on page 87)

Top left—Comparing *Donax* shell coloring for population studies; **Top center**—Studies of fish skulls for those interested in comparative anatomy; **To right**—Local echinoderms used in individual study problems; **Bottom left**—Examining *Limulus* for commensals; **Bottom center**—Interior view of labor tory; **Bottom right**—Making aquarium filters from plastic bottles and surplu tubing.

ASSOCIATION AFFAIR

Minutes of the Business Meeting, 17 April 1964

The business meeting was called to order by President Jones at 11:45 A.M., April 17, 1964.

SECRETARY'S REPORT: The secretary reported that 70 new members had joined the Association i 1964 and that the active membe ship totalled 1052 and that the were 24 Emeritus Members. H stated, also, that there were 39 li brary and institutional members an

(*Continued on page 99*)

AN APPRAISAL OF THE PRESENT STATUS AND FUTURE OF ESTUARINE-OCEANOGRAPHIC LABORATORIES OF THE SOUTHEAST[1]

Federal Laboratories With Special Emphasis on the Bureau of Commercial Fisheries Radiobiological Laboratory

T. R. Rice, *Director*
Radiobiological Laboratory, Bureau of Commercial Fisheries, Beaufort, North Carolina

Most of the laboratories in the southeastern nited States concerned with estuarine and eanographic research and supported by the deral government are Bureau of Commercial sheries laboratories. These laboratories are tuated along the Gulf and Atlantic Coasts from alveston, Texas to Beaufort, North Carolina, here the Radiobiological Laboratory is located. n addition to these laboratories, the Bureau of ommercial Fisheries has others located through- ut the United States including Alaska and awaii.

Federal Support of Oceanographic Research

The Federal Government, without doubt, is e largest single organization or agency sup- orting research in the United States. Recently, revolution has occurred in the interrelations of dustry, the federal government, and universi- es in mounting the nation's scientific effort, as own in the distribution of some $12 billion ent in a recent year on research and develop- ent. Industry used most of these funds. How- ver, the federal government furnished most of dustry's funds, all of the government's, and ost of the universities'.

Large scale research such as the Manhattan roject, which gave us the atomic bomb, and ASA, which claims it will put a man on the oon in the sixties, probably could not have een financed by any other organization than e Federal Government. Another large research rogram of the Federal Government is in the eld of oceanography.

Interest in oceanography has been aroused nd is increasing because man's knowledge of e ocean is limited indeed when compared with s importance to him. The time has come when is condition must be changed. To speed this change the Federal Council for Science and Technology has given the Interagency Committee on Oceanography the assignment of planning and coordinating programs in the science of oceanography sponsored by government agencies. Of the total money received for the National Oceanographic Program for fiscal year 1964, 40 percent will be spent on research, with the remainder going for supporting functions.

The Interagency Committee on Oceanography is composed of members from the Atomic Energy Commission, National Science Foundation, Public Health Service, the Smithsonian Institution, and Departments of Commerce, Interior, State, and Treasury. The Department of Interior received 12.1 percent of the National Oceanographic Program Budget for fiscal year 1964. A portion of these funds are allocated to the Bureau of Commercial Fisheries.

Bureau of Commercial Fisheries

The Bureau of Commercial Fisheries, which is a part of the U. S. Fish and Wildlife Service, is composed of four divisions (Figure 1). Estuarine and oceanographic research are conducted within laboratories under the Division of Biological Research. These laboratories come under the supervision of the four Branches of the Division of Biological Research: Anadromous Fisheries, Inland Fisheries, Marine Fisheries, and Shellfisheries.

In the southeastern United States the Bureau presently supports five laboratories. At Galveston, Texas the Biological Laboratory is concerned with shrimp biology and population dynamics, estuarine ecology, experimental biology, industrial bottomfishes, and the chemistry of sea water. The Biological Laboratory at Gulf Breeze, Florida is studying the environment in order to determine the effect of man on estuaries and the effects of pesticides on marine organisms. At the Biological Laboratory at Brunswick, Georgia systematics and life history studies of fishes of the western North Atlantic are being followed. There are two laboratories at Beaufort, North Carolina: the Biological Laboratory and the Radiobiological Laboratory. The biological Laboratory research is concentrated primarily on menhaden, blue crabs, and striped bass. The research of the Radiobiological Laboratory will be treated at greater length in this paper. In addition to these laboratories, the Bureau supports a number of field stations. Possibly the largest of these stations is located at St. Petersburg Beach, Florida. This station is studying estuarine ecology and the problem of red tide.

---

[1] The three papers printed here, by T. R. Rice, L. R. omeroy, and Albert Collier, respectively, were presented an invited symposium at the 25th annual meeting of e Association of Southeastern Biologists in Atlanta, eorgia, on 16 April 1964.

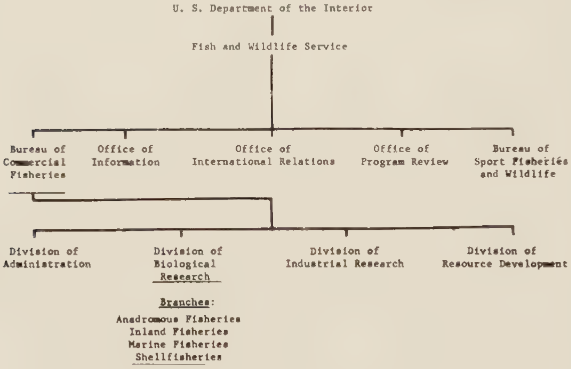

U. S. Department of the Interior
Fish and Wildlife Service
Bureau of Commercial Fisheries
Office of Information
Office of International Relations
Office of Program Review
Bureau of Sport Fisheries and Wildlife
Division of Administration
Division of Biological Research
Branches:
Anadromous Fisheries
Inland Fisheries
Marine Fisheries
Shellfisheries
Division of Industrial Research
Division of Resource Development

Figure 1.—Organizational chart of the Bureau of Commercial Fisheries, Fish and Wildlife Service.

Radiobiological Laboratory

The Bureau of Commercial Fisheries is vitally concerned with any situation that might adversely affect our fishery resources. The introduction of radioactive materials into the aquatic environment might constitute such a situation, and those in the Bureau who so quickly saw the need of a Radiobiological Program to study such problems deserve much credit for their insight. Although there now exists a widespread interest in radiobiology and many organizations in this country and throughout the world are engaged in radiobiological research, the Bureau's program carried on at the Radiobiological Laboratory was one of the first to be initiated and continues to be unique in many respects.

The Radiobiological Laboratory has the responsibility for advising the Bureau of Commercial Fisheries on matters pertaining to pollution from uses of atomic energy, for investigating instances of reported radioactivity in seafood, for training personnel in techniques of radioisotope application to fishery problems, and for carrying on research pertaining to basic aspects of fishery biology.

Atomic Plants and Power Reactors

An increasing number of atomic plants and power reactors are being planned or constructed by private industry under license by the Atomi Energy Commission. These are located o streams, estuaries, or the seacoast. All suc plants pose problems of possible radioactive con tamination of the environment. It is conceivabl that these plants or nuclear power reactors coul have some effect upon fish, shellfish, or wildlif in the surrounding area, since they release som radioactivity to the environment and raise th water temperature by the return of coolant wate heated in the reactor. Therefore, it is under standable that the local citizens and various fis and game organizations show their concern. There is need for assurance that the installatio creates no significant hazard in this regard. Th Fish and Wildlife Service, in order to carry ou its functions in protecting our fish and wildlif resources, we must keep informed of any activ ties which might have adverse effects on ou resources.

Fishing Industry

The fishing industry may be confronted a some future time with the problem of marketin seafood which supposedly contains radioactivit This could cause serious loss of markets. In suc situations there is a definite need for a Radio biological Laboratory within the Bureau of Com mercial Fisheries, so that the Bureau can be i a position to thoroughly assess the situatio The proper performance of such functions re quires a knowledge of the fate of radioactiv materials introduced into the aquatic environ ment. This knowledge has been gained large as the result of laboratory experiments con ducted along the lines of the original objective of the program.

Training

We have encouraged persons interested i acquiring training in radioisotope techniques t come to our laboratory. Our facilities have bee shared with graduate students, professors, Fis and Wildlife Service personnel, and foreign in vestigators. The rapid advances in this fiel require continual training of both new and ol employees of our own program. Our staff ha completed a training course given at our labora tory by the Mobile Laboratory Group of the Oa Ridge Institute of Nuclear Studies.

Organization of Research

The widespread use of isotopes produces host of related problems which can be solve more easily by investigators in related field working in the same laboratory than can be ac complished by individual investigators workin at separate locations. A group of such investi gators can offer: (1) a team approach in solvin problems, (2) more efficient use of costly equip ment needed for this work, (3) continuity to th esearch work, (4) convenience for sponsors of esearch, and (5) a much broader approach in he research program than available to an individual investigator. The staff of the Radiobioogical Laboratory has been organized with hese points in mind. The research interests re broad and the staff numbers 24, including Ph.D.'s.

The research of the Radiobiological Laboraory is divided into the broad areas of estuarine cology, biogeochemistry, pollution studies, and adiation effects (Figure 2). These four areas f research are called programs. Within each rogram are a number of projects. Each project eader has considerable freedom in planning the etails of his research, resulting in a wide variety f interests. For example, there are projects oncerned with ion transport in cells, producivity of estuaries, and trace elements in sea water. The four program chiefs, along with the aboratory director, considered the broader asects of the research program and decide when wo or more programs should cooperate in solvng problems too general to be handled comletely by a single program or project.

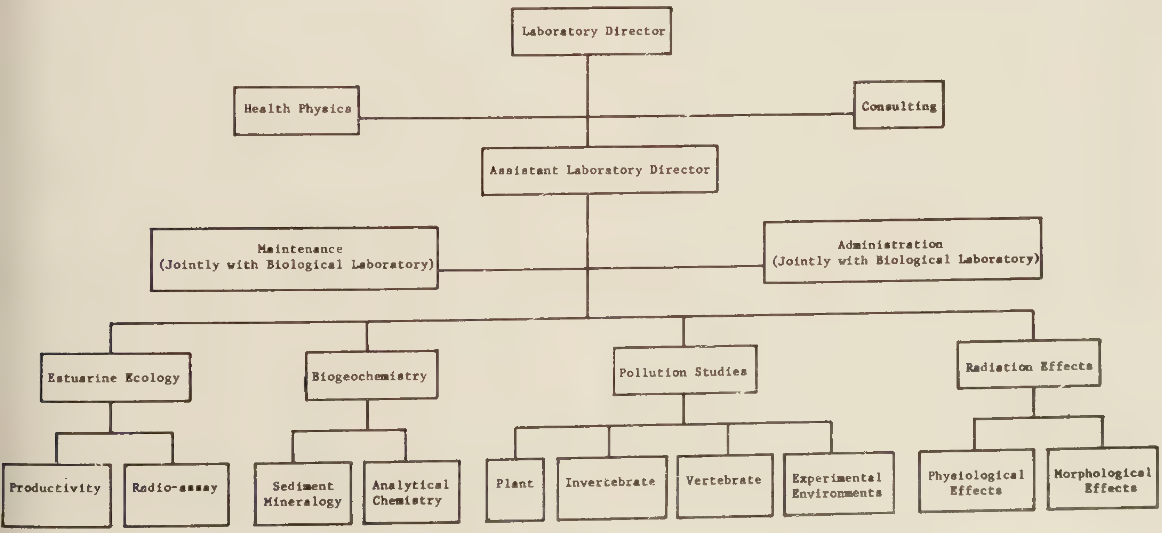
There are three general problems with which most research is concerned. These are: (1) the ate of radioactive materials in the marine environment, (2) the effect of radiation on marine rganisms, and (3) the application of radioacive tracers to fishery biology. In the past many data have been collected in the laboratory in order to be able to predict what might happen o radioactive materials introduced into the marine environment. More recently the use of anks and ponds has permitted the testing of questionable findings obtained in the laboratory. Present plans are to use certain natural bodies of water, restricted from the public, for observng the cycling of radioisotopes.

More complete and accurate information on the sensitivities of marine organisms to ionizing radiation is needed in order to predict and evaluate results occuring from radioactive contamination. The limited amount of data on the effects of radiation on marine organisms now available deals mostly with levels of radiation necessary to cause death or to severely alter the normal embryology and development of these organisms. One of the most probable effects of sublethal ionizing radiation is a change in the genetic material. With the new facilities of the Radiobiological Laboratory, a knowledge of radiation effects may be used to increase production of the marine environment since all mutations from radiation are not necessarily detrimental. With the use of radiation and controlled breeding experiments, larger, faster growing, and more resistant strains of commercially important species may be produced. Also, controlled irradiation may prove to be useful in eradication of undesirable species through sterilization or mutation.

Many new research possibilities have arisen in the field of fishery biology as radioactive materials have become available. The great sensitivity in the determination of radioactivity has made possible the application of tracers to problems beyond the range of standard methods. Radioisotopes have been used in fishery biology to (1) measure primary productivity, (2) determine feeding habits and rates and the extent to which "food" is utilized, (3) follow physiological processes, (4) determine the cycling of nutrients, (5) label or mark marine organisms, and (6) trace sediment and water movement.

The Future

Support for federal laboratories has increased in the last few years. The Radiobiological Lab-



IGURE 2.—Organizational chart of the Radiobiological Laboratory, Beaufort, North Carolina.

oratory has received appropriations for the design and construction of two laboratory buildings to be used specifically for radiobiological research. The larger facility, a two-story structure 188 feet long and 52 feet wide, will contain various types of laboratories, salt water rooms, offices, counting rooms, and special facilities for handling radioisotopes. The smaller building, 34 x 59 feet, will be used for studies of the effect of radiation on marine organisms. This building will house two cobalt-60 sources. One of these, a 50-curie source, will be placed in a 21 x 23-foot radiation room with 3-foot concrete walls and will be used for studies of the chronic effects of low levels of radiation. The other will be a self-contained drawer-type irradiator containing 1,500 curies of cobalt-60 and having a dose rate of 30,000 roentgens/hour. Organisms will be placed in a special chamber in the irradiator that will allow them to be maintained in flowing sea water while being irradiated. Construction of these buildings was completed in June 1964.

The rapid growth that has occurred in marine research in the southeastern United States during the last decade, no doubt, will continue. With the increased emphasis on oceanography, federal marine laboratories will grow in size and number. Already, the Bureau of Commercial Fisheries is building another laboratory. This new laboratory will be located at Miami, Florida near the University of Miami Marine Laboratory. It will be concerned with investigations of the Tropical Atlantic.

Cooperative Training Programs In Southeastern Marine Laboratories

L. R. Pomeroy
Marine Institute, The University Of Georgia

The demand for marine scientists is growing steadily, and it can be expected to continue to grow as we look to the sea for more resources. The present demand comes primarily from educational institutions and from federal and state agencies. As we move gradually from an age of exploration of the sea to one of utilization, more demands will come from industries for marine scientists.

Awareness of the demand for marine scientists is growing, but not fast enough. Many students in high schools and colleges still are being told that the only financially sound biological careers are in medicine. In fact, there are many. There is also a general lack of understanding about what marine biologists do and what their training entails. Most people associate marine biology with SCUBA diving. While this has a place in some kinds of scientific work, it is by no means the primary occupation of marine biologists. The marine biologist today is not a fish watcher. He gets the same training in a broad spectrum of basic sciences that any other biologist would. In fact, the training of the marine biologist is perhaps broader than that of some other biologists, because of his need to understand something about the physics, chemistry, and geology of the sea.

Probably the Southeast is not supplying its own needs for new marine biologists today, although the shortage of this commodity is worldwide. One way to broaden the base for training is through cooperative training programs. Not every university can have a marine laboratory or an oceanographic vessel, but cooperative training programs make it possible for landlocked universities to have an outlet to the sea for their students and faculty. Two cooperative programs exist in the Southeast today, at Duke University and at the University of Georgia.

The Duke University program in oceanography is starting this year. Cooperative fellowships for graduate students are available that will permit them to come to the Duke Marine Laboratory from other institutions and do their thesis research aboard the R/V *Eastward*. Faculty members of other institutions also may go on research cruises on the *Eastward*, and it is possible to take classes in marine biology or related subjects on short training cruises.

Over the past ten years the University of Georgia Marine Institute has permitted qualified graduate students from any university to reside at the Institute and use its facilities. Financial support for these students has varied, but typically they have been supported either through a grant to their major professor from a federal agency or by a fellowship from a federal agency. Students have come from such institutions as Emory University, the University of Michigan, Harvard, and Dalhousie. The research area includes the estuaries and the continental shelf.

There are some problems inherent in cooperative programs that we have come to recognize and expect. I shall mention some of them in the hope that it may help persons who are planning cooperative teaching or research programs.

For the graduate student there is the problem of diffuse, or at least remote, guidance. With his major professor at a distance, the student ay depart from his research plan when things) not go as anticipated. He may get conflicting lvice from various *ad hoc* sources. Some stu- ents are sufficiently mature and competent to void this pitfall, but many are not.

Even when the graduate student does have lvice from his major professor or his commit- e, this may leave something to be desired, if is of the mail-order variety. In one case, a udent obtained detailed written advice from is professor and every member of his commit- e, none of whom had ever visited the labora- ry or seen the study area. While we cannot ope to have seagoing doctoral committees, the ajor professor should be expected to know the udy area and the laboratory facilities. He hould present this information to the committee nd help the student both in formulating his roblem and in starting the actual research on e scene.

The basic problem, probably, is one of communication between persons and institutions. If cooperative training programs are to succeed, major professors must expect to put more than the usual time and effort into the programs. They must be regular participants in research at the cooperative laboratory, or at least they must be regular visitors who know at first hand the important research questions in their field and the technical or logistic problems that may be involved in solving them.

While this problem of communication can be a major one, recognition that it exists should help all concerned to keep active channels of communication. Cooperative research programs offer a great opportunity for broadening the course offerings and research capabilities of many universities. In research areas such as marine research, where specialized facilities are necessary, they may prove to be the answer to the need for more scientists.

State Supported Marine Laboratories: Their Missions And Related Specifications

ALBERT COLLIER
Oceanographic Institute, Florida State University

Any appraisal of a marine station, and its pres- nt or future plans must be made in the light of s mission. My contribution to this symposium oncerns those estuarine-oceanography labora- ories supported by states. One group of state upported laboratories is associated with the state niversity systems, and another group is a part f the state conservation agencies. The func- ions of the laboratories in these two cases are s different as the missions of the parent organi- ations.

The state conservation agencies are primarily oncerned with the control of the human utiliza- ion of renewable marine resources. The marine aboratories in this case exert their main efforts owards the development of information directly pplicable to the improvement of fisheries pro- luction. These efforts may take a negative form, uch as limitations on fishing seasons, areas, ypes of gear, and size of animals. Positive ap- roaches are taken when life histories, migration atterns, disease control methods, and other such roblems are attacked. All of this work is es- entially of the applied type.

In contrast to the state conservation agency narine laboratories we have the laboratories of he state universities, whose mission, of course, is ducation and research. The university curric- lum in marine science should be oriented to pro- ide graduates with the broadest possible formal background and the most intensive research experience available. To do this the faculty must engage in high quality research. The research must follow basic lines, and university teaching and research faculty should be chosen to assure that this direction will be followed. The results of basic research provide the nourishment for an advancing technology in numerous fields of human activity and the exploitation of the sea is no exception.

The university laboratory and the conservation agency laboratory should compose an effective team. The university supplies trained personnel and the stimulation inherent in creative basic research. The conservation agency can assist in supporting the work of faculty members and students in basic research which is beyond the scope of its mission.

Against this background of generalities I would like to discuss in more detail the principles guiding the planning and operation of a marine station which is a part of a state university.

The functions of the marine laboratory in this context are:

1) To supplement campus teaching by providing facilities for direct contact between students and the marine environment.
2) As a laboratory site for research on marine problems requiring continuous observation and/or running sea water.

3) As a base for collecting and storing living marine organisms to be transported inland.

4) As a base for floating equipment.

These functions are all extensions of the university campus and in themselves do not constitute complete programs in oceanography, since all the resources of a university campus are needed to back up such a program. Yet the shore laboratory, to be really effective must be as self sufficient as possible, intellectually as well as physically and logistically. This degree of self sufficiency can only be attained through the year round presence of a research staff, and this requires certain minimal facilities. The specific facilities for a given researcher will depend upon his interests, but there are certain types of general equipment with which such a laboratory should be furnished.

Perhaps the greatest problem in the successful operation of any shore establishment is that of isolation. People, generally are gregarious, and locations suitable for marine laboratories have a habit of ignoring that human instinct. Many of us welcome a few weeks at some isolated seashore for contemplation and the production of great ideas, but too much of a good thing can become noxious, especially to the permanent staff. Again the only answer is a situation in which transportation to and from the parent institution is reasonably simple; anything beyond a one-hour auto drive becomes burdensome. But even beyond this there must be sufficient staff to offer the spectrum of personalities necessary for a stable social environment.

From the point of view of political economics an establishment of proper size and substance for offering a good summer teaching and research program should be used 12 months per year instead of 3 or 4 months. Hence we are faced with the need to design a facility which is self-sufficient for year round operation and yet does not uneconomically duplicate campus assets.

The physical attributes most important in the consideration of a site for a shore facility are:

1) Proximity to the campus with easy access by auto.

2) Access to waters navigable to boats of suitable size.

3) Availability of reasonably clean sea water which is not subject to excessive variation in salinity.

4) Sufficient elevation to insure maximum protection against storm damage.

5) An abundance of high quality fresh water.

6) Proximity to a community of sufficient size to make convenient shopping for the daily needs of personnel.

7) Availability of electric power and telephones.

8) Sufficient area to permit construction of boat harbor, laboratories, residential and auxiliary buildings, experimental ponds and to allow room for future expansion.

9) Availability of a variety of marine environments.

The functional requirements of the laboratory building are (1) class rooms and student laboratories, (2) library, (3) museum, (4) aquaria supplied with running sea water, (5) laboratory rooms for individual investigators in all branches of oceanography, (6) general purpose rooms such as sterilizing room, distilling room, storage, shipping and receiving, etc. All of these features are required both for teaching and research functions. Of all these facilities, the most troublesome is the circulating sea water system. There is no easy answer. Not many years ago corrosion caused the most difficulty, and when this problem was solved by the introduction of industrial type glass and modern plastics, biological fouling became the dominant problem. In some localities suspended solids combine with biological fouling to make it very difficult to circulate useable sea water through a central system in a large laboratory.

The system most generally used is that of an overhead tank supplied by intermittent pumping from the sea. The supply and demand are adjusted to give sufficient time for suspended solids to drop out. However, the accummulated solids and related biota tend to establish an ecological system within the tank which must have some effects on the water leaving it to go to the laboratory, thus making controlled experimentation difficult or impossible in some cases.

The low turnover rate in the tanks does serve as a damping system on natural salinity and temperature fluctuations. The effectiveness of this action depends on the retention time in the tank.

The settling tank does not necessarily solve the problem of biological fouling, because the seaward intake is submerged and all of the lines between it and the settling tank are exposed to fouling if kept filled continuously. Intermittent emptying and drying, especially if there is a dual system, would be helpful. Perhaps the most easily controlled system would be that in which a high velocity, high pressure flow is used. The high velocity within the walls of the pipes makes attachment of organisms practically impossible. A necessary feature of this approach is the "through-flow" or "open-end" pumping of water. In other words the discharge line from the pump is "run by" the table taps, etc. in such a way that water which is not needed goes into a wasteline. This permits maximum velocity at all times. A variation on this last arrangement is possible in the elimination of the settling tank. In other words the water flow is direct to the laboratory;

nd in cases where there is no appreciable load f suspended solids this would probably be the nost satisfactory of all systems. In two cases have used this system for as long as four years, vith very little time lost on breakdowns. The rincipal objection to these systems is the use of continuously operating pump and the conseuent power bill.

Another promising idea for sandy beach areas, ut untried as yet so far as I know, is the contruction of a sump in the open sea, or estuary, s the case may be. The construction of the ump is simple in principle—it calls for a walling-n and roofing over of a small piece of sea botom, say 20′ in diameter. The walls could be onstructed of sheet piling and with a roofing of lastic to keep out spray and drifting debris. he bottom is left open. In sandy areas (this dea would not work where the bottom is rocky) eepage up through the bottom should supply a ltered water supply with a minimum of susended material. The capacity of the sump vould be a function of the total floor area and he type of sedimentary materials composing the ea bed. If this idea is sound it would make ossible a system of considerable reliability and conomy. Fouling organisms as well as susended solids will have been removed by filtraion through the sea floor.

A second feature in the general layout of a narine station really combines two items: a pier nd a boat harbor. The pier is one of the most seful tools at a marine station. It provides a table platform on demand; if it reaches far nough to the seaward it offers water sampling nd animal collecting at a variety of depths and rom a variety of bottom types. If the site is not ocated on a rocky coast, boulders can be placed t suitable points along the pier to add environnental variety. At the shore end of the pier quaria can be set up and supplied with running vater, thus combining observations of animals in aptivity with those collected in the open water rom the pier.

The boat harbor can be constructed in conunction with the pier with some gain in total ffectiveness. The exact plan would depend of ourse, upon the local terrain. In any event one ide of the pier, suitably widened and strengthned, could serve as the main landing for the aboratory boat. On the opposite side the boat-ervicing area should be located. This would nclude a marine ways, constructed so as to pernit the "hauling-out" of the boat for safety in ase of an impending hurricane. The boat haror should include a ramp for launching outoard rigs and a dry-storage boat-house for small oats in the service of the laboratory.

At an isolated spot in the boat harbor there hould be a fueling dock. Fire hazards should e reduced to a minimum.

Suitable arrangements for the transfer of materials from the boat to the laboratory is an often overlooked convenience. Depending again upon the locale, this might simply mean locating the laboratory door at dockside, or the provision of a lift or crane and suitably designed wheeled conveyances for transporting equipment and specimens. Whatever the solution to the problem, it should not be left to chance.

Up to this point we have discussed that part of a marine station which involves its physical contact with the sea. There remains the internal organization of the laboratory itself.

A starting point would be the recognition of the general functions of the laboratory and the physical layout needed to support them. The summer teaching program has already been mentioned and obviously class rooms and laboratories are central in this respect. Teaching students in direct contact with the marine environment is the most effective way possible to stimulate deep and continuing interest in the subject. The number of students should be as many as resources will allow. It is doubtful that teaching of this nature should be based on the lectures supplemented by laboratory work. The converse of this would be more appropriate, namely laboratory work supplemented by lecturing. In this light a combination laboratory-class room may be the more economical approach. Such a room should be supplied with running sea water and aquaria at each table in addition to larger holding tanks centrally located in the laboratory. The student's lab benches should be designed for a variety of technical operations typical of oceanography—: handling of cores and analysis of sediments, plankton sorting, photometric determinations of chemical attributes, conductivity and specific gravity experiments, light absorption experiments and others. The laboratory teaching would be done as a background for related works in the field.

Teaching work of this nature is not very productive without adequate library facilities. A carefully selected library should be available, but there should be no attempt to stock complete files of all the desireable serial publications. All recent texts, reference books, current files, and selected journals, should be available. A state-supported laboratory might be in a better situation with respect to library services. Certainly in the case of Florida State University the main campus library is available within an hour's drive of the laboratory.

A museum is as important as the library from the point of view of teaching. The collections should include plants, animals, and geological specimens. All should be properly curated.

When students are learning new groups of animals, classifying the algae from field collections, or attempting to analyze core collections, reference collections are necessary.

Since graduate teaching is one of the important activities at a marine station and graduate students are for the most part beginning research scientists, an atmosphere of scholarly research must be created as a part of the normal environment. This can only be done through active research performed by scientists who spend most of their time at the laboratory.

It is necessary to provide laboratories for a variety of research areas in oceanography, each with its own peculiar suites of equipment and furnishings. There should be some staff members working at the laboratory almost continuously, with a generous seasoning of visiting investigators.

The Florida State University laboratory at Alligator Harbor is cited here as a state operated laboratory with which I am most familiar at the moment.

When evaluated according to the criteria discussed in the preceding paragraphs, we find the Alligator Harbor laboratory somewhat deficient. It served its purpose well as a beginning, but today the pace is faster and we are planning now for a completely new laboratory at a new site. We have already mentioned the need for a facility sufficiently complete to make it a desireable place for full time, resident investigators. It is our belief that these improvements will bring our shore laboratory into the high degree of usefulness that it should have. The site now being sought offers several important improvements over Alligator Harbor. Water depths in channels to carry vessels up to 6 feet in draft can be obtained. The building sites are of sufficient elevation to prevent damage by hurricane tides. Some 100 acres of land will make future additions possible. On this property facilities meeting the general criteria set out above will be constructed.

In the past the shore facility of the Florida State University Oceanographic Institute has been a biological station. We hope that it will become an oceanographic station encompassing all the varied interests and disciplines that make oceanography what it is.

This means that it shall become more than a collecting base and a place for transient visitors who would not be so transient if suitable facilities are available.

In short, it will be a place where students and investigators of the oceans can bridge the gap between the campus classroom and the open sea.

Martin D. Young Appointed Director of the Gorgas Memorial Laboratory in Panama

Carl M. Johnson, Director of the Gorgas Memorial Laboratory, Republic of Panama, will become Director Emeritus on July 1, 1964. Appointed to succeed Dr. Johnson as Director is Dr. Martin D. Young, who recently retired from the Commissioned Corps of the United States Public Health Service. Before his retirement, Dr. Young served as an Associate Director of the National Institute of Allergy and Infectious Diseases, Bethesda, Maryland.

Dr. Young, one of the world's leading authorities on malaria and tropical diseases, has received many honors for his contributions to research, especially in the field of malaria. In 1963 he was the recipient of the Darling Foundation Medal and Prize awarded by the World Health Organization. Only ten other malariologists have ever been so honored. Recognition of his outstanding service was also made in 1953 when he received the Rockefeller Public Service Award and again in 1946, 1952, and 1960 when he was co-winner of the Jefferson Award of the South Carolina Academy of Science.

Most of Dr. Young's research on malaria was conducted at Columbia, South Carolina, where he was head of the field station of the Laboratory of Parasite Chemotherapy before coming to Bethesda in 1961. His research there was concerned with all phases of malaria, particularly the use of malaria parasites in the treatment of neurosyphilis. During this period he contributed important knowledge of malarial drug resistance and documented cases that showed parasite resistance to the very drugs which have been among those used most effectively in suppressing and curing malaria.

Since 1950 Dr. Young has served as a member of the Expert Panel on Malaria of the World Health Organization. In 1957 he was a consultant of the International Cooperation Administration mission to the Government of India where he assisted in evaluation of malaria control in that country. He was subsequently named an Honorary Fellow of the National Society of India for Malaria and Other Mosquito-borne Diseases. He had acted as consultant on malaria to World Health Organization and Pan American Health Organization.

A native of Moreland, Georgia, Dr. Young is a member of numerous honorary and scientific societies. He was the first president of the American Society of Tropical Medicine and Hygiene. Currently he is president-elect of the American Society of Parasiologists.

SARASOTA: Spawning Ground For Marine Biologists

JOHN D. WOOLEVER
RIVERVIEW HIGH SCHOOL, SARASOTA, FLORIDA

During the past five years, there have probably een as many budding marine biologists pawned in a quiet Gulf Coast community as here have been in any of several marine biogical stations. Here there is a noted marine aboratory, two high schools, a science museum, junior college and an NSF sponsored summer nstitute offering programs in marine biology. One of these institutions is the result of chilren's interest in their environment, a conscienous school system, and the efforts of some outheastern biologists.

Six years ago, several students at Riverview High School, in Sarasota, Florida, prevailed pon their biology teacher to permit them to *extend* their biology studies" in the laboratory, ather than be enrolled in a study hall. The igh school biology course in which they were nrolled was emphasizing the study of *local* lant and animal life, rather than depending pon commercially preserved specimens, which requently did not represent life as the students aw it every day. Since Sarasota is a city on the Gulf Coast, marine organisms made frequent ppearances. As the biology course progressed, t was noted in this new school that even though many of the students lived on the coast most of heir lives, they had little knowledge of local marine life. The growing population coming rom the north presented a similar situation, with hundreds of students seeing many and trange organisms which they had only read bout in books such as Buchbaum's *Animals Without Backbones.* These requested "extended tudies," meant—"learn more about the sea and ts residents."

Within three months, more than a dozen students had their study hall membership transerred to a group which soon spent its time tudying marine invertebrates. As is natural for his age group, a biology club had formed, and by January, they were sending packages of marine specimens to other biology clubs all over the United States, including Alaska, and, of course, the interior of Florida.

Collecting, dissecting, preserving, reading, and studying habitats is not enough if you really have an interest in biology. Keeping them alive and studying behavior is probably more interesting than anything else. This meant hauling in saltwater, aerating, filtering, and resisting corrosion. These problems led to an interesting solution which resulted in students from many parts of the United States coming to Riverview High School to study Marine Biology. This past summer, approximately eight high school biology teachers and eighteen students of high ability from many parts of the United States were enrolled in a NSF program, jointly sponsored by the Cape Haze Marine Laboratory and the Sarasota Board of Public Instruction. Most of the work was conducted at the Riverview Laboratory, where facilities are much like the typical marine station anywhere in the country. Chief instructor of the program was Dr. Harold J. Humm of Duke University, former director of both the Florida Oceanographic Institute and the Duke University Marine Station. Conditions are far different from those first encountered by the pioneering students who struggled to keep their specimens alive with only an aquarium pump and a few gallon-jars.

Inasmuch as the science facilities needed expansion, particularly to accommodate the growing numbers of biology students at Riverview, it was decided that one of the laboratories, with minor modification, could be constructed for the study of marine organisms. The school property is bounded by a creek that empties into nearby Sarasota Bay. Instead of adding a room to the main structure, a separate "portable" type structure, 26 by 50 ft., was erected near the creek. It adjoins some wild property which is being considered for the development of an outdoor laboratory, to fit in with another part of the school's biology program.

The air-conditioned building has high windows, which permit extensive use of adjustable shelves along the walls yet can be darkened easily for visual aids by using heavy drapes. Countershelves with storage space beneath offer added working space in addition to the laboratory tables. Along the countershelves, an extensive aerating system can service more than two hundred aquaria. This air line is paralleled by a line of electrical outlets and fluorescent lights. The latter supplies not only supplementary light for microscopes, but is used in selective lighting for plant experimentation.

The center of the room is occupied by three large water tables made of cypress, lined with glass. Freshwater and saltwater systems serve these tanks, as well as aerator outlets and overhead lights. Plastic pipe is used for both the air and saltwater. The saltwater system consists of two connecting concrete tanks located underground, where they can be easily drained or filled.

In addition to the standard cabinets holding the microscopes, collections, chemicals, and the usual biological materials, the room has tote-tray cabinets, a refrigerator, deep freeze, and oven. From past experience, it was decided that the laboratory tables should not be hampered by being tied down to gas lines. Instead, portable compressed gas units, in addition to the large stove and small electric hot plates, serve as sources of heat. This allows for mobility of desks for small or large working surfaces. Salinometers, centrifuge, autoclave, scales, and many other standard laboratory items are available for use by students.

The course offered is primarily a survey of local marine life, and oceanography with marine chemistry limited only by the students' chemical backgrounds. Although the ecology, anatomy, and physiology of local phyla are stressed, the students spend much of their time developing group and individual studies in animal behavior.

Over the years, students and teachers have been working on a vertical file by soliciting reprints at every opportunity. For the average high school there is an extraordinary library on marine life. Four books are used by each student as basic texts, ranging from the popular *Edge of the Sea* by Rachel Carson to *Natural History of Marine Animals* by MacGinitie and MacGinitie. The reason for this range is due to the nature of the students enrolled. It is considered an enrichment class, even though it is a "second level" course. Any student with a satisfactory grade in high school biology may enroll. This permits any student interested in any phase of marine life to participate in the offering. An attempt is made to satisfy each student's interests and needs: a tenet of the Sarasota Public School system.

Students electing to take the course are scheduled to have a free period before or after the scheduled marine classes which meet the last two periods of the day. The ordinary class period lasts fifty minutes daily, but by having a study hall before or after the regular marine class, field trips can be arranged during the school day for two periods, and may extend for some time after school. It is not uncommon to have students enroll in the class every year until graduation. As they have discovered, the course is not identical year after year. They serve as laboratory and field assistants, while studying an organism which they select and maintain from year to year. These students are also given the responsibility of maintaining the continuity studies conducted by the classes from year to year. These include a tagging program of fishes, invertebrates, growth studies, drift bottles, and others.

The Cape Haze Laboratory, under the direction of Dr. Eugenie Clark, is a short distance from the Riverview facility. As an educational service, Dr. Clark permits students to use the laboratory's library and frequently has some of the more able students assist in some of the studies underway at Cape Haze. One of the original marine students is presently employed at Cape Haze. Several are at Florida universities studying biology, with plans to major in some phase of oceanography.

Having had several years experience with budding marine biologists, the Cape Haze laboratory graciously consented to co-sponsor the Cooperative College-School NSF program, thereby lending additional material resources and the services of scientific personnel in an instructional and advisory capacity.

n reflecting upon the history and development this unique high school facility and the enhing activity offered to students in this area, is interesting to note the influence that rearch biologists and university personnel can ve upon public school education. After the st year of this program, when the instructor as considering the termination or expansion of e program for the following year, several mane biologists were consulted. Many hesitated advise and did not commit themselves. Two ell-known regional biologists stated emphatilly that the study of marine biology was far ove and beyond high school students. They id it should be left to college students who would get a taste of it at the senior college or graduate level. One biologist, however, who had taught many high school students, felt the program should be continued. This suggestion was supplemented with personal resource materials as well as encouragement and advice.

During the 1964 NSF-sponsored summer program, only a limited number of teachers and students benefitted directly from the instruction afforded by Dr. Humm, the gentleman who was such an encouraging university mentor of this project. However, it would be difficult to estimate the untold numbers whose careers will indirectly be moulded by his personal interest and unselfish efforts.

The AAAS Montreal Meeting

DECEMBER 26-31, 1964

THE 131ST MEETING of the American Asciation for the Advancement of Science will clude sessions of 20 AAAS sections and of me 76 participating organizations. Programs particular interest to biologists are:

oving Frontiers of Science I. One of two speakers the evening of Dec. 26 will be V. C. Wynne Edwards, University of Aberdeen, whose topic will be "Self-Regulating Systems in Populations of Animals." Henry Eyring will preside.

AAS Distinguished Lecture. Lord Brain, consulting physician to London Hospital and Maida Vale Hospital for Nervous Diseases; retiring president, British AAS, will speak on "Science and Anti-Science" the evening of Dec. 27. L. Paul Dugal, Dean, Pure and Applied Science, University of Ottawa; General Chairman of the Meeting, will preside.

oving Frontiers of Science II. One of two speakers the afternoon of Dec. 28 will be Clement L. Markert, Johns Hopkins University. His topic will be "The Role of Genes in Embryonic Development." Alan T. Waterman will preside.

fth George Sarton Memorial Lecture will immediately follow Clement L. Markert. Lloyd G. Stevenson, Professor of the History of Science and Medicine, Yale University will speak; Wilder G. Penfield, Honorary Consultant, Montreal Neurological Institute, McGill; Honorary General Chairman of Montreal Meeting, will preside.

AAS Interdisciplinary Symposia. Two of the four interdisciplinary symposia, all on the morning of Dec. 28, are:

1. "Medical Geology and Geography," arranged by Harry V. Warren, University of British Columbia, who will preside. Other speakers include Helen Cannon, U. S. Geological Survey, Denver; Arthur Furst, Institute of Chemical Biology, University of San Francisco; Anna H. Koffler, Ohio Northern University; and R. J. F. H. Pinsent, College of General Practitioners, Birmingham, England.
2. Part I of the five-session symposium, "Biochemical Differentiation," arranged by Norman Kretchmer, James D. Ebert, Robert E. Greenberg, and Oscar Touster. This session on "Protein Synthesis: A Fundamental Problem in Embryology and Differentiation," besides Norman Kretchmer, who will preside, has as speakers: James D. Ebert, and Mahlon Hoagland. James D. Ebert's vice presidential address will be "Interacting Systems in Development."

International Conference and Symposium on Primate Behavior. Six open sessions Dec. 27-31 inclusive. Sponsored by the combined Section of Animal Behavior and Sociobiology of the Ecological Society of America and the same Division of the American Society of Zoologists, cosponsored by the AAAS Sections in Zoological Sciences (F), Anthropology (H), and Psychology (I), and by the American Psychiatric Association and American Psychological Association. The program chairman is Stuart A. Altmann, University of Alberta. Speakers from four continents, include:

A. Stuart A. Altmann, Alison Jolly, Makerere College, Kampala, Uganda; Paul E. Simonds, University of Oregon; Thelma Rowell, Makerere College; Gordon D. Jensen, University of Washington; Leonard A. Rosenblum, Downstate Medical Center, Brooklyn;

B. Hans Kummer, Delta Regional Primate Center, New Orleans; John H. Kaufmann, University of Florida; Jeanne Altmann, University of Alberta; Yvett Spencer-Booth and Robert A. Hinde, Cambridge University, England; Stephen Gartlan, Bristol University, England;

C. Films and Tapes.

D. Martin Moynihan, Canal Zone Biological Area, Smithsonian Institution; Junichiro Itani, Kyoto University, Japan; K. Ronald L. Hall, Bristol University; Irwin Bernstein, Yerkes Laboratory of Primate Biology, Orlando, Florida;

E. Jean-Jacques Petter, Laboratoire de Physiologie, Faculte de Medicine de Paris; Yukimaru Sugiyama, Kyoto University; Suzanne Ripley, University of California, Berkeley; Thomas Struhsaker, University of California, Berkeley; John Vandenbergh, Laboratory of Perinatal Physiology, National Institutes of Health;

F. Robert E. Miller, University of Pittsburgh; Brian W. Robinson, Stanford Medical Center; Atsuo Tsumori, Japan Monkey Center, Aichi-Ken, Japan; C. Ray Carpenter, Pennsylvania State University.

AAAS Section F—Zoological Sciences. Contributed papers, Dec. 27; Biologists' Smoker, Dec. 27, eve.; and Zoologists' Dinner and vice presidential address by Arthur D. Hasler, Dec. 29, eve.

AAAS Section G—Botanical Sciences. The two-session symposium "Plant Biology Today V," Dec. 29, is a continuation of the four-year series of basic papers for teachers. Luncheon and vice presidential address by Harriet B. Creighton will be Dec. 29. Sessions for contributed papers, Dec. 30.

AAAS Section N—Medical Sciences. Remaining four sessions of the symposium, "Biochemical Differentiation," arranged by Norman Kretchmer, James D. Ebert, Robert E. Greenberg, and Oscar Touster, Dec. 29, 30. Topics and speakers are:

A. Oögenesis and Fertilization—Daniel Mazia (Chm.), Joseph Gall, Fred H. Wilt, David Epel, Paul Gross;

B. Cytodifferentiation—Clifford M. Grobstein (Chm.), Stanley Cohen, Irwin Konigsberg, Norman Wessells;

C. Sequential Appearance of Proteins during Differentiation—Eugene Knox (Chm.), Norman Kretchmer, John Papaconstantinou, Olga Greengard;

D. Regulatory Phenomena—Sol Spiegelman (Chm.), Ulrich Clever, H. O. Halvorson, Howard Hiatt.

AAAS Section O—Agriculture. Six-session symposium "Pest Control by Chemical, Biological, Genetic, and Physical Means," arranged by Edward F. Knipling, Dec. 27-30.

SOCIETAL PROGRAMS

American Astronautical Society. Two-session symposium on Bioastronautics, Dec. 29.

American Fisheries Society and **Biometric Society, ENAR.** Joint two-session symposium on "Population Estimation," arranged by Douglas S. Robson, Dec. 29.

American Nature Study Society. Annual meeting, Dec. 27-30.

American Physiological Society, National Academy of Sciences Space Science Board, and NASA Office of Space Science and Applications. Invited papers on space biology and medicine, arranged by Robert E. Smith, Dec. 27.

American Society for Microbiology. Two symposia, "Pleuropneumonialike Organisms," arranged by J. Gershon-Cohen, and "Viruses and Cancer," by Charles Panos, Dec. 30.

American Society of Naturalists. Annual meeting will include a two-session symposium "Cytoplasmic Units of Inheritance," Dec. 27, and the presidential address of Albert Tyler and business meeting, Dec. 28.

Biomedical Information-Processing Organization. Symposium on "Classification Problems in Medical Diagnosis," arranged by Max A. Woodbury.

Ecological Society of America. Program, arranged by George M. Woodwell and George W. Barlow, Dec. 26-31, includes several symposia, sessions for contributed papers on plant and animal ecology, and sessions on animal behavior (in addition to the International Conference on Primate Behavior already mentioned).

Entomological Society of Canada, Société Entomologique du Québec, and the **Lyman Entomological Museum.** Contributed papers by the two societies, Dec. 30, and an anniversary celebration at the Museum.

Mountain Lake Biological Station "Alumni." Annual breakfast for all persons who have been students, investigators, or staff members at the station, Dec. 29.

National Association of Biology Teachers. The annual national meeting, Dec. 27-30.

National Geographic Society. Special Film, "My Life among Wild Chimpanzees," by Jane Goodall, Sub-Department of Animal Behaviour, Cambridge University, England, Dec. 30. Stuart A. Altmann will be the commentator.

Sigma Delta Epsilon. National meeting will include a tea for all women in science, Dec. 28, and the annual society dinner meeting, Dec. 29.

Society of Economic Botany. Contributed papers, dinner, and business session, Dec. 30.

Society of the Sigma Xi. Sixty-fifth annual convention, luncheon, and joint address with Phi Beta Kappa, by René Dubos, Dec. 29. H. Bentley Glass will preside.

The **AAAS Exposition of Science and Industry** and the **AAAS Science Theatre,** with recent foreign and domestic films, will be prominent features of the meeting. Coupons for sleeping accommodations and advance registration will be found in *Science* from July 17 on.

IVEY FOREMAN LEWIS

1882-1964

Dean and Professor Emeritus Ivey Foreman ewis died in Charlottesville, Virginia, on March , 1964.

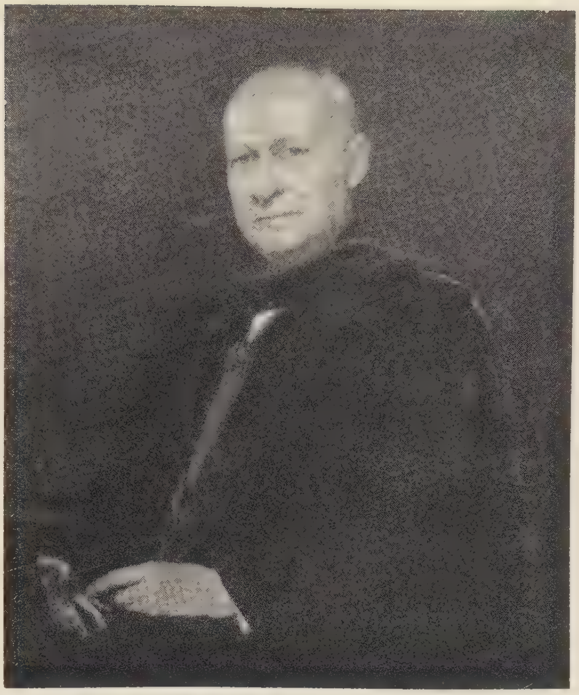
Dean Lewis was born in Raleigh, North Car- ina. He received his A.B. and M.S. from the niversity of North Carolina, and his Ph.D. om the Johns Hopkins University. The Doctor Science degree was awarded Dean Lewis by e University of North Carolina in 1947.

In 1908 Dr. Lewis studied at the University of onn, working under Edward Strasburger. Dur- g the same year he held the Smithsonian Table the Stazione Zoologica at Naples.

Upon recommendation of the Miller Board of rustees to the University of Virginia Board of isitors, Dr. Lewis was appointed Miller Profes- r of Biology and Agriculture, beginning in Sep- mber, 1915. From that date until his recent tirement, Dr. Lewis has served the University many fields of endeavor other than as Profes- r of Biology. In 1934 he was appointed Dean the University, served as Director of the ountain Lake Biological Station from 1933 to 46, and was appointed Dean of the College or rts and Sciences in 1946.

Dean Lewis served as a member of the Na- onal Research Council from 1928 to 1932, was member of the Executive Committee from 1930 rough 1931, Vice Chairman of the Division of iology and Agriculture from 1933 through 1936. He was a trustee of Biological Abstracts, Fel- w of the A.A.A.S., Secretary, Vice-President, nd President of the Botanical Society of Amer- a, President of the American Biological So- ety, and President of the American Naturalists. e was a member of Phi Beta Kappa, Omicron elta Kappa, the Raven Society of the Univer- ty of Virginia, and as a member of the Society Sigma Xi was most instrumental in having a apter of that society established at the Uni- rsity of Virginia.

In December, 1920, Dr. Lewis founded the ssociation of Virginia Biologists, an organiza- on which has been superseded by the Virginia cademy of Science. He was instrumental in or- nizing the latter in May, 1923, and served as first president.



IVEY FOREMAN LEWIS

HENRY G. GOOD

1897-1964

Henry G. Good, Professor of Zoology and Entomology at Auburn University since 1924, died of a heart attack April 10, 1964. During his period of service at Auburn, he taught approximately 12,000 students, served as advisor to students in zoology, and participated in many other activities of interest to students and the University.

Dr. Good was born in Ohio in 1897, and was reared in California. He held the B.S. degree from the University of California at Berkeley and the M.S. and Ph.D. degrees from Cornell University. He was a member of Phi Kappa Phi, Sigma Xi, and Gamma Sigma Delta honor societies. He was also a member of Sigma Pi social fraternity and was advisor to the local chapter. He was a member of the Entomological Society of America, Alabama Academy of Science, and an honorary member of the Alabama Ornithological Society. He had served as president of the Faculty Club of Auburn University, and participated in civic as well as academic affairs.

J. T. PENNEY

1900-1964

J. T. Penney, Professor of Biology and head of the Department at the University of South Carolina, died suddenly following a heart attack on March 29, 1964.

J. T. PENNEY

Dr. Penney was a native of Charlotte, North Carolina, and received his A.B., M.A., and Ph.D. from the University of North Carolina. He taught high school in Charlotte, North Carolina, and at the University of Tennessee School of Medicine, Memphis, Tennessee, before joining the University of South Carolina in 1929. He was promoted to the rank of full Professor in 1945, and at one time served the University as Dean of Men, Director of Student Activities, and Professor of Biology. He was appointed Head of the Department of Biology in 1959, and served in this capacity until his death.

He was a Past President of the South Carolina Academy of Sciences, the LeConte Scientific Society, and the Association of Southeastern Biologists and was also a charter member of the ASB. Dr. Penney was a member of the American Society of Zoologists and Sigma Xi.

Author of a large number of published scientific works, both articles and monographs, Dr. Penney conducted extensive investigation of sponges, and made important contributions to the taxonomy and biology of fresh water species. He was a member of a team from the University of South Carolina that studied the biology of the Atomic Energy Commission's Savannah River Plant in its early days.

The loss of Dr. Penney to the University of South Carolina will be felt in many ways. He was a man who had strong opinions on many things—and his dedication to teaching and his sincere interest in students and their academic progress was an important part of his personal make-up and character. It was under his guidance that the Department of Biology grew, and although of the "Old School" in training and early experience, Dr. Penney never failed to keep up with the times.

PAUL J. ARNOLD

1896-1964

Paul J. Arnold, Chairman of the Division of Sciences and Mathematics at Jacksonville State College, Jacksonville, Alabama, died at University Hospital in Birmingham.

Dr. Arnold was born in Wheatley, Ky., July 1, 1896. He received his A.B. from Georgetown College, Ky., and his M.S. from Peabody College. Dr. Arnold received an honorary Doctorate of Science from Georgetown College.

His teaching career began in the schools of Scott County, Ky., 1919-21. From 1921-25, Dr. Arnold served as Superintendent of Schools Augusta, Ky., and 1925-29 in the same position in Williamstown, Ky.

His career at Jacksonville began in 1929, when he served as an Associate Professor of Biology. In 1932 Dr. Arnold became acting head of the Department of Biology. In 1935 he became Professor and Head of the Science Department. In 1947 he assumed the position of Professor and Chairman of the Division of Sciences and Mathematics, in which capacity he served until his death.

G. MILES CONRAD

1911-1964

G. Miles Conrad, director and trustee of Bio-ogical Abstracts, Philadelphia, died unexpectedly at his home on September 9.

A world-recognized expert in the field of communication of scientific information, Mr. Conrad had served in many prominent positions at both he national and international level. Prior to is appointment at Biological Abstracts, Mr. Conrad was associated with the Library of Congress as a documentation specialist (1950-53); s editor, Graphic Science Associates, Inc., New York (1948-50); as technical editor and market esearch director, Hazard Advertising Company, New York (1943-48), and as assistant curator of Comparative and Human Anatomy, American Museum of Natural History, New York (1934-3).

He received the A.B. degree from Oberlin College in 1933 and the M.A. from Columbia University in 1938. From 1936-39 he participated in six scientific marine expeditions for the American Museum of Natural History. Mr. Conrad was awarded the Bronze Star and Conspicuous Service Cross for service in the China-Burma-India Theatre during World War II.

His numerous publications include scientific esearch articles in comparative anatomy, ichthyology and paleontology; popular biology, and documentation.

EZDA DEVINEY

1895-1964

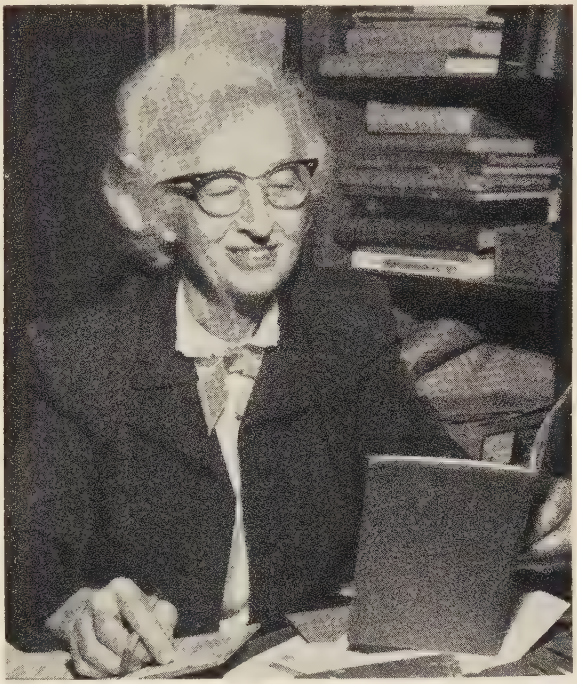
Ezda Deviney, Emeritus Professor of Zoology, at the Florida State University, died of a heart attack in Greensboro, N. C. on March 19, 1964.

Dr. Deviney was head of the Department of Zoology at the Florida State University for several years, and in 1957 she received the Meritorious Teaching Award given by the Association of Southeastern Biologists.

A native of Julian, N. C., she completed her undergraduate work at Woman's College of the University of North Carolina in 1919, and started as an Instructor in the same school. In 1921-23 she held a similar instructorship at Salem College in Winston-Salem, N. C.

After receiving her M.S. from the University of Chicago, she went to Tallahassee. Later study at the University of North Carolina earned her the Ph.D.

At Florida State College for Women, and its successor, Florida State University, she taught practically every zoology course offered. She served as president of the Alpha of Florida chapter of Phi Beta Kappa, which was organized at Florida State in 1935, and was first president of the Florida State Sigma Xi Club. Other memberships included the American Association for Advancement of Science, the Florida Academy of Science, the Association of Southeastern Biologists, and the National Association of Biology Teachers.



EZDA DEVINEY

Books and Periodicals

A new booklet, entitled *Alabama Trees,* is now available through the University Book Store, Auburn University, to students and others interested in common trees of the State. Authors are Dr. Donald E. Davis and Dr. Norman D. Davis, Department of Botany and Plant Pathology.—The booklet consists of two parts. Part I contains instruction and keys to be used to identify 172 species of Alabama trees. The authors have attempted to include all native trees, all introduced trees that are now reproducing in the wild state, and most of the common cultivated trees in Alabama. Alphabetical lists to both scientific names and common names are included. Part I also includes six plates illustrating key features of leaves and stems, a glossary of all technical terms used in the key, and a list of pertinent additional references. Part II of the booklet by I. R. Martin, forester, Cooperative Extension Service and W. B. Devall, head, Department of Forestry, contains pictorial illustrations of 77 of the most common trees of the State and pertinent information concerning each tree.—The booklet has been prepared especially for use in elementary botany courses.

Books received recently

The following books have been recently received by the ASB. Should any member of the ASB wish to review one of these books in return for the review copy, please write to *Mrs. Betty Ursomarso, Assistant Editor, Academy of Natural Sciences, 19th & The Parkway, Philadelphia 3, Penna.*

STURTEVANT, A. H. AND G. W. BEADLE. 1964. *An Introduction to Genetics.* Dover Publications, Inc., New York. 391 pp. $2.00. (A Dover Reprint.)

PENNAK, ROBERT W. 1964. *Collegiate Dictionary of Zoology.* The Ronald Press Co., New York. 583 pp. $8.50.

SHELFORD, VICTOR E. 1963. *Ecology of North America.* University of Illinois Press, Urbana. 610 pp. $10.00.

Foundations of Modern Biology Series—2nd Edition

(Prentice-Hall, Englewood Cliffs, New Jersey)

The Cell, by Carl P. Swanson. 1964. 118 pp. $1.75 (paper); $3.95 (cloth).

Animal Diversity, by Earl D. Hanson. 1964. 118 pp. $1.75 (paper); $3.95 (cloth).

Cell Physiology and Biochemistry, by W. D. McElroy. 1964. 120 pp. $1.75 (paper); $3.95 (cloth).

The Plant Kingdom, by Harold C. Bold. 1964. 118 pp. $1.75 (paper); $3.95 (cloth).

Adaption, by Bruce Wallace and Adrian M. Srb. 1964. 115 pp. $1.75 (paper); $3.95 (cloth).

Chemical Background for the Biological Sciences, by Emil H. White. 1964. 152 pp. $1.95 (paper); $4.95 (cloth).

Growth and Development, by Maurice Sussman. 1964. 116 pp. $1.75 (paper); $3.95 (cloth).

Animal Behavior, by V. G. Dethier and Eliot Stellar. 1964. 118 pp. $1.75 (paper); $3.95 (cloth).

Heredity, by D. M. Bonner and S. E. Mills. 1964. 115 pp. $1.75 (paper); $3.95 (cloth).

The Life of the Green Plant, by A. W. Galston. 1964. 118 pp. $1.75 (paper); $3.95 (cloth).

Animal Physiology, by Knut Schmidt-Nielsen. 1964. 118 pp. $1.75 (paper); $3.95 (cloth).

Foundations of Modern Genetics—New Series

(Prentice-Hall, Englewood Cliffs, New Jersey)

The Mechanics of Inheritance, by Franklin W. Stahl. 1964. 171 pp. $4.95 (cloth).

Extrachromosomal Inheritance, by John L. Jinks. 1964. 177 pp. $2.95 (paper); $4.95 (cloth).

Human Genetics, by Victor A. McKusick. 1964. 148 pp. $2.95 (paper); $4.95 (cloth).

Agricultural Genetics, by J. L. Brewbaker. 1964. 156 pp. $2.95 (paper); $4.95 (cloth).

Concepts of Modern Biology Series

(Prentice-Hall, Englewood Cliffs, New Jersey)

Molecular Biologys Genes and the Chemical Control of Living Cells, by J. M. Barry. 1964. 139 pp. $3.35.

PRIMARY EMBRYONIC INDUCTION. Lauri Saxén and Sulo Toivonen, Logos Press, Prentice Hall. 1962. $8.75.

There was a great surge of excitement among the embryologists of the 1920's following the discovery of the "organization center" by Hans Spemann and Hilde Mangold. After a few years of rather feverish activity the capabilities and limitations of the living organization center were described. When it became known that inductions with non-living material are possible, the stage was set for the orderly progression of synthetic and analytical studies that were carried out in the 1930's. With quiet optimism teams of workers conducted experiments that would surely, it seemed, result in the characterization of "the" evocator, but the embryonic heritage of the 1940's was largely great masses of inconclusive data. Work in this area was rather uninspired until the 1950's brought fresh ideas and some new techniques.

The time has not yet come to tie up the problem of primary embryonic induction in a neat little bundle and mark it solved, but the resurgence begun in the 1950's has produced enough results to make a comprehensive and analytical discussion of them worthwhile. Such a discussion has been provided for us by Saxén and Toivonen.

There are several textbooks that give very good and comprehensive accounts of the earlier work on induction,

t for the sake of completeness and order, Saxén and
ivonen go over it again in their first three chapters.
their fourth and fifth chapters on the responding tissue
d on heterogenous inductors, they begin to introduce
e more recent information. Chapters six and seven
al with what is known of the physical and chemical
ture of the primary inductors and chapter eight is set
de for a short treatment of the immunological ap-
oach to the problem of induction. Finally, in chapters
ne and ten the various theories that have been elabo-
ted to explain primary induction are recounted, dis-
ssed and evaluated extensively in the light of experi-
ental data.

In this book a great many diverse pieces of informa-
n are brought together and thoughtfully arranged.
e authors have critically and candidly, but without ap-
rent bias, discussed the findings and views of a num-
r of different investigators. Their own work is (quite
turally) particularly well presented, but is not given
due emphasis.

The beginning graduate student and the zoologist who
interested in induction but who has not followed its
erature closely in recent years should find this book
rticularly helpful. It is written and illustrated with
usual clarity.—J. N. DENT, UNIVERSITY OF VIRGINIA.

DVANCES IN MARINE BIOLOGY, vol. 1. F. S. Rus-
ll, Ed. xiii + 410 pp., 1963. Academic Press, London
d New York. $13.50.

This series was initiated to "help biologists to keep
breast of knowledge in the different lines of research on
e biology of marine organisms." An annual volume
ill be issued, each with a wide variety of review arti-
es. Emphasis will be placed on fishery sciences in
hich the results of many studies are being published in
latively inaccessible journals.

The first volume contains five interesting articles. In
e first, "Rearing of Bivalve Molluscs" (pp. 1-136),
ictor Loosanoff and H. C. Davis summarize the im-
ortant work on rearing bivalves carried out at the U. S.
ureau of Commercial Fisheries Biological Laboratory at
ilford, Connecticut. Roughly half of the article is con-
erned with mechanics of rearing larvae in the laboratory
d effects of different conditions on eggs and larvae.
pecific information is included on 19 species.

A posthumous article by Anton Bruun, "The Breeding
the North Atlantic Freshwater-Eels" (pp. 137-169),
an unfinished manuscript in which Bruun attempted to
swer some of the points raised by D. W. Tucker con-
erning the "Atlantic eel problem." Bruun supports
hmidt's theory of two breeding populations in the
orth Atlantic, basing most of the present article on
hmidt's original data. Although Bruun was able to
swer some of Tucker's arguments, the problem is by
means settled.

J. A. Nicol, in the third article "Some Aspects of
otoreception and Vision in Fishes" (pp. 171-208),
ncentrates on summarizing recent findings on photobe-
avior and the functioning of the eye in the marine
bitat. Topics include extra-ocular reception, regulation of light at sensory surfaces, visual pigments, and the chorioidal gland.

C. M. Yonge provides an interesting survey of recent studies in the fourth article, "The Biology of Coral Reefs" (pp. 209-260). As might be expected from Yonge's long interest in tropical reefs, the article is restricted to recent findings on reef-building, tropical corals. Such topics as systematics and distribution, settlement of planulae, zooxanthellae, erosion, and growth, among others, are included. Suggested lines of research can be found throughout the article.

The final paper, "The Behaviour and Physiology of Herring and Other Clupeids" (pp. 261-393), by J. H. S. Blaxter and F. G. T. Holliday, is a detailed review of the biology of *Clupea harengus* and about a dozen other clupeids, in which the life histories of these species are followed in some detail. Behavior and physiology based on aquarium experiments and on observations at sea are included; their behavior in relation to fishing gear has been stressed. The authors point out that although the herring is probably the most intensively studied of the fishes, many aspects of its basic biology are unknown. They also suggest that a better knowledge of behavior and physiology will help to solve fisheries problems.

Each of the articles is accompanied by an extensive bibliography. There is an index to authors mentioned in the articles and the bibliographies and a skeleton subject index is included.

This useful volume will prove to be a welcome addition to the library of any institution in which the marine sciences are studied, taught, or practiced. It is hoped that future volumes will be as interesting.—RAYMOND B. MANNING, U. S. NATIONAL MUSEUM.

SYMPOSIUM ON MARINE MICROBIOLOGY. Carl H. Oppenheimer, Ed. C. C. Thomas, Springfield, Ill., 1963. xviii + 769 pp. Illus. $22.50.

The word symposium stems from the Greek symposion, meaning feast. We have here a sumptious smorgasbord of sixty-six papers by eighty-eight authors, representing the first international meeting on marine microbiology held in Chicago in 1961. It seems fitting that the opening contribution should be by Claude E. ZoBell, the grand old master of marine microbiology, who succinctly summarizes the dominant ecological problems attending marine microorganisms, thus setting the stage. It is not clear why his original, fetching title, The Sea Around Us Microbiologists, was transmuted into the sombre Domain of the Marine Microbiologist. There follow four other reports which collectively constitute an introduction, each author reviewing a group of papers within the six topical divisions into which the symposium was conveniently arranged: producers and their relation to the chemical and biological environment; geomicrobiology; ecology of algae, protozoa, fungi, and viruses; bacterial distribution and function; mineralization; while one such division dealing with heterotrophy has somehow not been similarly treated.

It is salutary to note that today, when a microbiologist is hardly considered *au courant* unless he is tracing the lineage of fragments of DNA or sRNA, there is a robust and increasing number of workers happily engaged in the largely descriptive efforts to elucidate the roles of microorganisms in the sea. Although the individual reports vary in the usual way in length and content, they seem uniformly surcharged with a subtle enthusiasm. To sample a few: S. W. Watson isolated nitrifying bacteria from the Atlantic morphologically different from *Nitrobacter* and *Nitrosomonas;* M. B. Allen believes the blue-green alga, *Calothrix,* to be a possibly indigenous aerobic nitrogen-fixer, and suspects the yeast *Rhodotorula;* some feasible explanations for the existence of thermophilic bacteria in polar regions are set forth by R. H. McBee; J. C. Lewin describes the nutrition of several species of diatoms which grow well in the dark; S. P. Meyers and E. S. Reynolds account for the degradation of lignocellulose by species of the deuteromycete *Zalerion* and the ascomycetes *Torpedospora* and *Halosphaeriopsis;* Marine yeasts are well surveyed by J. W. Fell and N. van Uden; R. Spencer briefly reviews marine bacteriophages; L. Moewus incriminates a holotrichous hymenostome ciliate as a viral vector; F. W. Ochynski and J. R. Postgate report some biochemical differences between fresh water and marine strains of sulfate-reducing bacteria; R. A. MacLeod discusses the need for sodium by marine bacteria and reports the isolation of a sodium-independent mutant; H. W. Jannasch studied the chemostatic growth of a spirillum when the growth-limiting substrate, asparagine, was supplied decreasingly while the dilution rate remained unchanged; J. Liston and R. R. Colwell report on host and habitat interrelationships of commensal bacteria; A. I. Zhukova reports on the contribution of microorganisms to the nutrition of aquatic invertebrates; F. D. Sisler, who has been interestingly involved with electrical energy from biological fuel cells and with the possible presence of organisms in meteors, now turns his attention to the role of the earth's magnetic field in the creation of electrical potential differences in the sea and their possible effects on microbiological activities. Ferguson Wood, the lone Australian, laments in two or three papers the paucity of fiscal largess in marine microbiology; my impression from a visit to his country's marine research establishment at Cronula was that as long as there is ample animal protein on the hoof the Aussies will not give a hoot for the sea. Then, if one believes that it is essential to possess a laboratory on the beach and an expensive ocean-going vessel in order to do justice to marine microbiology, there is an excellent, but disquieting, paper from R. E. Kallio and his co-workers from the middle of Iowa detailing the mechanisms of bacterial oxidation of alkanes, an area that has fallen within the purview of marine microbiology.

There is clearly enough here for almost anybody. This volume should provide a plethora of ideas and exciting problems not only for the microbiologist but for the biologist generally, and I recommend it to your critical attention. One can no longer balk at the price of a book of such impeccable craftmanship, including large type on super-glossy paper, especially when I recently spotted a scientific volume listed at $100. However, I would have preferred to see this publication in double-column, off-set printed, at less than half the cost; one important objective of a symposium, after all, is dissemination. Fifty pages are devoted to an alphabetical listing of the references which appear at the end of each presentation; this will appeal to some workers, but I have a strong aversion to duplication, and would certainly have liked to see these fifty pages used for the discussion, which is entirely omitted. In fact, I would like to see the scientific community adopt an unwritten law that would proscribe publication of a symposium unless the complete discussion, preferably verbatim, is included. The Cold Spring Harbor symposia might well serve as a model.—J. Q. Heplar, Old Dominion College.

A PHYTOTRON FOR THE SOUTHEAST

Scientists at Duke University and North Carolina State at Raleigh wish to inform their colleagues that they are planning the construction of a two-unit phytotron, which will provide extensive controlled environment facilities for investigators in the Southeast, as well as for their own staff members. The concept of a two-unit phytotron was developed in order to make the greatest possible use of the scientific talent residing on the two campuses. Each unit will specialize in research in areas where it is strongest. North Carolina State will be particularly concerned with research in population genetics, plant pathology, and entomology, although several other departments expect to make use of the phytotron. At Duke University, research on ecological and physiological problems concerned with the distribution of natural vegetation and research on trees will receive special attention from members of the botany and forestry staffs.

The Duke University unit will consist of a group of air-conditioned greenhouses attached to a large two-story building which will house plant growth rooms and chambers, offices, laboratories, and air-conditioned equipment. Preliminary plans call for six 16 by 24 ft. greenhouses and about 40 plant growth rooms and chambers of various sizes and characteristics. About a dozen of these will be 9 by 12 ft. walk-in rooms to operate at temperatures of 25 to 95°F. Another group of chambers will be 4 by 8 ft., and a number of small reach-in type chambers will be included for seedlings and small plants. Most of the rooms and chambers will provide at least 3000 foot candles 36 inches below the lights. Special humidity control will be provided for a few, and there will be limited control of humidity in most of the growth chambers.

Offices and some laboratory space for visiting investigators will be included in the building, which will be completely air-conditioned.

Because of space limitations, the unit at North rolina State will consist of a three-story build- ; with greenhouses on the roof. The principal int growth rooms and chambers will be similar those used in the Duke unit, but arranged newhat differently. Special sections will be lated from the main structure for use by path- gists and entomologists.

It is estimated that the Duke unit will cost proximately $1,500,000; the North Carolina ite unit, $1,750,000. North Carolina State has tained $750,000 from the Z. Smith Reynolds undation of Winston-Salem, and Duke Uni- rsity will provide $250,000. The National ience Foundation has granted $383,150 to start nstruction, and it is anticipated that it will rnish additional support in succeeding fiscal ars. It is expected that both units of the phy- ron will be in operation within three years.

Construction of this phytotron is an important p forward for science in the Southeast be- use this region has relatively few large scienti- facilities other than those related to medical search. The construction of this important search tool should be a strong stimulus to aduate training and research in the entire utheast. In fact it might well result in devel- ment of nationwide or even a worldwide cen- r for research on the effects of environmental ctors on living organisms.

The planning and construction of the two units is being coordinated by a Phytotron Board, consisting of two members from each campus plus a director appointed by the presidents of the two institutions. The members from North Carolina State are K. R. Keller and H. F. Robinson, those from Duke are W. D. Billings and H. J. Oosting. P. J. Kramer is serving as chairman. This board is expected to supervise the research programs and correlate the activities of the two units to make them as effective as possible.

Eventually we expect to organize a regional advisory board of scientists interested in this type of research, who will assist in developing a research program which will be of the greatest possible usefulness to the Southeast. Meanwhile we hope that persons interested in this type of research will write us about their needs so we can take them into account in our planning. If enough interest develops, we might hold a one-day conference this fall to give those interested an opportunity to inspect the plans and offer suggestions.

Scientists who have strong interests in research involving the use of controlled environment facilities are invited to write Paul J. Kramer, Department of Botany, Duke University, Durham, North Carolina, or other members of the phytotron board.

News of Biology in the Southeast

bout People

Robert A. Woodmansee, formerly of the University of uthern Mississippi faculty, has been appointed to the rginia Institute of Marine Science research staff. Ac- rding to Dr. William J. Hargis, Jr., Director of the stitute, Dr. Woodmansee will head marine plankton idies at the Gloucester Point research facility.

Leonard O. Morrow has joined the faculty of Rich- ond Professional Institute as Assistant Professor of ology. Mr. Morrow is currently completing his doc- rate in Botany at Cornell University and will develop vanced courses in Botany at R.P.I.

Ralph E. Thorson, Professor and Head of the Depart- ent of Biology, University of Notre Dame, has been anted a leave-of-absence to serve as professor of para- ology and tropical health, School of Public Health, nerican University, Beirut, Lebanon. **Robert E. Gor- on**, Associate Professor of Biology, has been appointed ting-head of the department, **Brother Raphael Wilson, S.C.**, assistant head, and **Joseph A. Tihen**, as editor The American Midland Naturalist, University of Notre ame. All appointments are effective September 1, 64.

B. Theodore Cole, Professor of Biology, has been ap- inted Head, Department of Biology, University of uth Carolina, Columbia, S. C.

Burton J. Bogitsh, formerly Assistant Program Director, Division of Scientific Personnel and Education, National Science Foundation and Professor of Biology at Georgia Southern College has joined the faculty at Vanderbilt University as Associate Professor of Biology.

William H. Adams, former Professor of Biology at Tennessee Wesleyan College, has accepted a position as Dean of the School of Arts and Sciences at Tennessee Polytechnic Institute effective September 1.

Robert F. Drescher joined Sharpley Laboratories, Inc. as Vice-President on July 15, 1964. For the past 10 years Dr. Drescher has been Chief Microbiologist, Paper Section, Buckman Laboratories, Inc., Memphis, Tenn. Prior to this he was a graduate student of Dr. Clyde Christensen at the University of Minnesota. Dr. Drescher will be active in stream pollution research, the microbiology of pulp and paper, and industrial mycology at Sharpley Laboratories, Inc.

Nell B. Causey joins the staff of Louisiana State University to teach an undergraduate course in invertebrate zoology and a graduate course in taxonomy. Dr. Causey, who will continue her work on millipedes, spent the summer vacation at the British Museum of Natural History.

Arthur L. Applegate, who received his Ph.D. from Emory University, will teach graduate and undergraduate embryology at Louisiana State University.

After postdoctoral work at Washington State University, **Albert M. Meier** will teach vertebrate physiology at Louisiana State University. He will continue his research in avian physiology.

Wallace D. Dawson, Assistant Professor of Biology, Department of Biology, University of South Carolina, has been awarded a $24,064 research grant by the National Institutes of Health for a three-year study of genetic factors in hybridization.

John D. Reynolds and **Mrs. Rowena G. Matthews** have been appointed Instructors in the Biology Department, University of South Carolina.

John Plymale has been appointed Assistant Professor of Biology at Howard College, Birmingham Ala. Dr. Plymale received his degree from the University of Alabama. His principal field of interest is parasitology.

Lynn Raulerson, Assistant Professor of Biology, returns to the staff at Howard College, Birmingham, Ala., after one year of graduate work toward her Ph.D. in zoology at the University of Georgia.

James Dobie has accepted the position of Assistant Professor at Howard College, Birmingham, Ala. Dr. Dobie received his degree from Tulane University. His field of interest is vertebrate zoology.

Howard J. Teas, program director for metabolic biology with the National Science Foundation, is joining the University of Georgia in Athens as Chairman of the Division of Biological Sciences September 1, 1964.

C. Theresa Cali has joined the faculty of the Department of Biology and Genetics, Medical College of Virginia, as Interim Assistant Professor. She was formerly Assistant Professor of Biology at Auburn Community College. Dr. Cali's major interest is evolution of nematodes. The same department is host to Petrona D. Noblejas, M.D., Instructor in Anatomy, University of Santo Tomas, Phillipines, who has begun a two-year visit under auspices of the Agency for International Development. Dr. Noblejas, whose major interest has been embryology, will establish a subsection of genetics upon her return to the University of Santo Tomas.

Institutions and Organizations

The Department of Biology at **Tennessee Wesleyan College,** under the Chairmanship of William H. Adams, has been awarded a $16,000 matching grant for the purchase of undergraduate instructional scientific equipment by the National Science Foundation.

The Department of Zoology at Tulane University has established the **George Henry Penn Memorial Award** for outstanding graduate research in zoology by Tulane graduate students. The initial recipient of this award is Doctor Aelita Pinter, whose dissertation, "Effects of nutrition and photo-period on reproductive physiology, growth, and malnutrition in *Microtus montanus*," was judged the most outstanding for the period June 1, 1963-May 31, 1964.

The **Virginia Institute of Marine Science at Gloucester Point, Virginia** has been conducting three programs this summer sponsored by the NSF. The **Research Participation for College Teachers Program,** the **Undergraduate Science Education Program,** and the **Cooperative College-School Science Program** held at Norview High School, Norfolk, Virginia. There have been four participants in the RPCT program working on individual research for twelve weeks, ten undergraduate students working with staff members for ten weeks, and fifteen high ability students and three teachers working under the supervision of Dr. Sewell H. Hopkins for eight weeks.

The Biology Building at **Howard College,** Birmingham, Ala., was dedicated in honor of Alabama industrialist, Thomas D. Russell. The building has been air-conditioned, and two greenhouses and a walk-in cold room added. Other equipment, amounting to $60,000, will be added.

The Department of Biology and Genetics at the Medical College of Virginia will be a principal beneficiary of a $230,000 fund received from NIH and the Commonwealth of Virginia for renovation of laboratories in McGuire Hall. During the past year the Department has expanded to occupy 52 per cent more space.

THE NOMINATING COMMITTEE for 1965 consists of Dr. Alvin Beatty of Emory University; Dr. George Kent of Louisiana State University; and Dr. E. Ruffin Jones of the University of Florida, *Chairman*. In order to help this committee with its task, please fill in the form below (or write a letter if you do not wish to mutilate the *Bulletin*) and mail to Dr. Jones as soon as possible. The deadline is January 1, 1965.

SUGGESTED NOMINEES FOR ASB OFFICES AND EXECUTIVE COMMITTEE POSITIONS

To the members of the Nominating Committee:

I wish to suggest that you consider the following ASB members in selecting nominees for offices and executive committee positions:

PRESIDENT-ELECT ....

VICE-PRESIDENT ....

TREASURER ....

EXECUTIVE COMMITTEE MEMBERS (2 for 3-year terms) ....

....

Deadline: January 1

Mail to: DR. E. RUFFIN JONES, DEAN
College of Arts and Sciences
University of Florida
Gainesville, Florida

(*Continued from page 78*)

nine foreign countries were
resented by 18 members. It was
ved and seconded that this report
approved. The motion passed.

TREASURER'S REPORT: The
asurer called attention to his re-
t as published in the Vol. 11, No.
sue of the Bulletin. He then pre-
ted his report for the January 1–
il 10, 1964 period. A motion was
de and seconded to accept his re-
t. The motion passed.

UDITING COMMITTEE: The
ort of the committee which stated
t the books of the Association had
n examined and found to be in
er was read by President Jones.
motion to accept the report was
de and seconded. The motion
sed.

OETHE AWARDS: The report
the committee was read by Dr.
rgaret Menzel in the absence of
Chairman of the committee. She
orted that 18 applications for fi-
cial assistance had been received
that all had been approved. A
al of $511.00 was expended in
port of the awards. A motion was
de and seconded to accept the re-
t. The motion passed.

CONSTITUTION AND BY-
WS COMMITTEE: No report.

MEETINGS COMMITTEE: The
airman of the committee reported
t an invitation for the Association
meet at the University of Virginia
1965 and at the North Carolina
te College in 1966 had been ac-
ted. A motion to accept the re-
rt was made and seconded. The
tion passed.

RESOLUTIONS COMMITTEE:
e Chairman of the committee
sented the report. A motion was
de and seconded to accept the
ort. The motion passed.

NOMINATING COMMITTEE:
e Chairman of the committee
mitted nominations for the fol-
ving offices: President-Elect, Vice
sident, Secretary and two Exec-
ve Committee members. Nomina-
ns from the floor were called for
there being none a motion was
de and seconded to close the
minations. The motion was
sed. President Jones announced
t the results of the election would
given at the annual banquet.

President Jones reported that the Southern Section of the American Society of Plant Physiologists had become the first affiliate of the Association and that its representatives on the Executive Committee would be Dr. Frederick T. Wolf.

President Jones then raised the question of affiliation with AIBS as an Adherent. He presented some of the objections to such a relationship and called attention to the action of the Executive Committee on April 16, 1964 which was embodied in the following motion:

> WHEREAS, The ASB in full accord with the aims and objectives of the AIBS, and WHEREAS, the ASB wishes to cooperate with all interested in the efforts to strengthen Biology:
>
> We encourage members of the ASB to become members of AIBS and to work toward an arrangement whereby ASB could continue to support AIBS in some special category on the same or similar basis as in the past.

The floor was opened for questions and after a brief period a motion was made and seconded to adopt the policy embodied in the motion. The motion passed.

President Jones called to the attention of the membership the passing of Dr. James T. Penney, Chairman, Department of Biology, University of South Carolina and two Emeritus Members, Dr. Ezda M. Deviney and Dr. Ivey F. Lewis.

He then expressed his appreciation for the support given him as President of the Association.

There being no further business the meeting was adjourned at 12:45 P.M.

August 1964 ASB Bulletins sent to the following people were returned by the Post Office with notations that the addressees had moved and left no forwarding addresses. Our records show that their membership dues are paid up to date, and that they should be receiving the bulletin. If anyone knows the whereabouts of any of these people, please notify *Mrs. Betty Ursomarso, Assistant Editor, Academy of Natural Sciences of Philadelphia, 19th & The Parkway, Philadelphia, Pa. 19103.*

Julian T. Darlington
Dept of Biology
Furman University
Greenville, South Carolina

Wanda S. Hunter
Zoology Dept.
Duke University
Durham, North Carolina

Irving E. Gray
Zoology Dept.
Duke University
Durham, North Carolina

John D. Reynolds
Biology Dept.
Coker College
Hartsville, South Carolina

LETTERS

Thank you for publicly and effectively saying in your **ASB Bulletin** editorial, "The National Register As A Privacy Invader—Where Do We Go From Here?" what many other biologists must have strongly felt. In fact this is the first time that I have rebelled and refused to fill in any National Register questionnaire at all; each time I picked up the latest form, my misgivings about the new information it demanded greatly overcame my considerable desire to co-operate.

My feelings about this sort of thing not only exactly reflect the points you express, but also include deep resentment (that is surely thought perverse by those legions of true believers in expediency) that we must redesign our vital statistics —even our lives—to fit the needs of machines, instead of doing things the other way around.

J. Ives Townsend
Medical College of Virginia

I have just read the article on literature citation in the July ASB bulletin. I should like to say that I am in your corner in this fight . . . The appearance in print of your comments coincide with several fruitless hours spent in the library trying to second guess a 19th century German who published something in "Zool." The abbreviation saved 6 characters of print and cost me nearly that many hours of work in the library. Congratulations on your stand and I wish us all luck.

Walter J. Harman, Chairman
Department of Zoology and
Physiology
Louisiana State University

Congratulations on the editorial in the last ASB Bulletin "Literature Citation Abbreviations—a Waste of Time," and also on the one concerning the National Register.

I've felt the way you do about those abbreviations for years. But they occur not only in the bibliography, but also in the text itself of taxonomic papers. Just this morning I got a reprint and there is the same old pointless phenomenon: The names of the species are centered over the descriptions and despite the space on each end, the authority names are so abbreviated as to require Sherlock Holmes to work some of them out. Taylor is "Tayl" for example!

The whole business boils down to the fact that scientists just won't think for themselves; they'd rather do things in the same old way just because their instructors did it that way. But I suspect editors are a little involved in this also.

Harold Humm
Dept. of Botany
Duke University

I have read the article by you and Miss Ursomarso entitled "Literature Citation Abbreviations—A Waste of Time," which appeared in the ASB Bulletin, pages 71-73, Volume 11, July 1964.

I agree entirely with your ideas. Full literature citations are very helpful to scientific readers. I find that I can more readily recall the content of an article if the title is cited. If the title is omitted, it is often necessary to look up the article.

In 1940 Dr. Coatney and I published a note "Reference citations and micro film" in Science, Volume 2, page 429, in which we expressed some of the same ideas in connection with micro film.

Martin D. Young, Sc.D.
Director
Gorgas Memorial Laboratory
Balboa Heights, Canal Zone

Some one has sent me a copy of the *ASB Bulletin* (how did you come to publish in a serial with an abbreviated title?) containing the article by you and Miss Ursomarso on citation of literature. Seeing that I am one of the time-wasters whose work in this kind you mention, I feel impelled to a few remarks of my own.

It seems to me your contention is, in the main, sound, though your title is not (does it really take more time to write an abbreviation, even if you have to look it up, than to copy the full title?). Your thesis accords with a change, just beginning, among taxonomists in citing authority for botanical names. Abbreviations here have certainly outlived their usefulness, and in several key places such authorities are now being cited in full ("A. P. de Candolle" instead of "DC."; "Lamarck" instead of "Lam."; and so on).

But you weaken your case by some exaggeration and certain inaccuracies. Taking the larger of your two bibliographies (a wrong use of that word, by the way; they have no real claim to such a title), I note that 8 of the 70 entries are books, not abbreviated in either column. Is that quite fair? I could show you hundreds of papers in which no books are cited. And a further 7 entries in your "unabbreviated" list are "ibids." If they are not abbreviations, I don't know what is! And to most editors of technical work they are unacceptable abbreviations (so many authors revise their list of references and add new ones—and one new reference in the midst of a flock of ibids can jumble the whole thing. It happens!).

If you take out the ibids and the book-publishers, together about 20 per cent of the list, your statistics may turn out a bit different. You would still have a case, perhaps not quite so striking but more free from possible controversy.

A slight inaccuracy is your statement that a period is equivalent to a single dropped character; you must know that this is not true. However, in our work here we have judged it *nearly enough true* so that we do not replace one character by a period. We *have* abbreviated "Comptes" to "Compt." (perhaps absurdly); but not "Compt." [for "Compte ́].

I agree with you that much abbreviation is—or at least seems to be—nonsense. But when you consider the very large proportion of authors who cannot cite the titles of papers—even their own—correctly, do you think that their attempts to copy the titles of serials would be much more informative than the customary abbreviations? May I point out, in defense of our own list of abbreviations, that we have always considered (and stated in our introduction) that much of its value is the provision of complete and accurate titles of serials and information on their provenance. An unabbreviated title *can* be as misleading or mysterious as an abbreviated one—*more so* than our abbreviations for some of the duplicated or often changed titles. How much is the full title, anyhow? Everything on the title page? (I have not checked you on this point, to see whether you really did use the full titles in your list! If so, which title-page—that of the issue or that of the volume? They often differ. Have you had occasion to cite some of the technica publications of Latin American departments of agriculture? It's a puzzle to know just how much is title and how much besides the title one should include to avoid error or confusion; and my guess is that, without some such list as ours, a dozen scientists will cite the same serial in half a dozen different ways even when they are attempting to cite i in full! In short, the problems o citing literature are not settled by simply avoiding abbreviation; and sometimes they are aggravated thereby!

H. W. Rickett
New York Botanical Garden

RADIOBIOLOGICAL RESEARCH

T. R. RICE

Bureau of Commercial Fisheries
Radiobiological Laboratory
Beaufort, N. C.

Reprinted from UTILIZATION AND CONTROL OF PESTICIDES
AND RADIOACTIVE MATERIALS

The Fifty-Sixth Meeting NORTHEASTERN RESOURCES COMMITTEE
Rowe, Massachusetts

April 8, 1964

RADIOBIOLOGICAL RESEARCH

by

Dr. T. R. Rice
Radiobiological Laboratory
Bureau of Commercial Fisheries
Beaufort, N. C.

An increasing number of atomic plants and power reactors are being planned or constructed by private industry under license by the Atomic Energy Commission. These are located on streams, estuaries, or the seacoast. All such plants pose problems of possible radioactive contamination of the environment. It is conceivable that these plants or nuclear power reactors could have some effect upon fish, shellfish, or wildlife in the surrounding area since they release some radioactivity to the environment and raise the water temperature by the return of coolant water heated in the reactor. Therefore, it is understandable that the local citizens and various fish and game organizations show their concern. There is need for assurance that the installation creates no significant hazard in this regard. The Fish and Wildlife Service, in order to carry out its functions in protecting our fish and wildlife resources, must keep itself informed of any activities which might have adverse effects on our resources.

The fishing industry may be confronted at some future time with the problem of marketing seafood which supposedly contains radioactivity. This could cause serious loss of markets. In such situations there is a definite need for a Radiobiological Laboratory within the Bureau of Commercial Fisheries, so that the Bureau can be in a position to thoroughly assess the situation. The proper performance of such functions requires a knowledge of the fate of radioactive materials introduced into the aquatic environment. This knowledge has been gained largely as the result of laboratory experiments conducted by the Radiobiological Laboratory along the lines of the original objectives.

The research of the Radiobiological Laboratory includes the broad areas of estuarine ecology, biogeochemistry, pollution studies, and radiation effects (Figure 1). These areas of research are called programs. Within each program are a number of projects. The project leader has considerable freedom in planning the details of his research. Similarly, program chiefs, along with the laboratory director, decide to a large extent the direction research will take and exploit opportunities which might arise for two or more programs to cooperate in solving problems too involved or complex to be handled completely by a single program. The staff consists of 24 members, eight of whom have Ph.D. Degrees.

There are three general problems with which most research is concerned: (1) the fate of radioactive materials in the marine environment, (2) the effect of radiation on marine organisms, and (3) the application of radioactive tracer techniques to fishery biology. To obtain this data three approaches have been used (Table 1). In the past much data has been collected in the laboratory in order to be able to predict what might happen to radioactive materials introduced into the marine environment. More recently the use of tanks and ponds has permitted the testing of questionable findings obtained in the laboratory. Present plans are to observe the cycling of radioisotopes in certain natural bodies of water, restricted from the public. In our opinion data collected by these three approaches, when integrated and correlated, will make for a better understanding of the role of plants and animals in the cycling of radioactivity in estuaries and marine areas.

The Fate of Radioactive Materials in the Marine Environment

Radioactive materials, upon being introduced into a marine environment, will appear in a soluble state or form particles. This, to a large extent, will influence the cycling of individual radioisotopes through the three components (water, sediments, and biota) of the environment (Figure 2). This cycling can be expressed as the three R's: routes, rates and reservoirs. Each radionuclide takes a characteristic route had has its own rate of movement from component to component prior to coming to rest in a reservoir, one of the three components of the marine environment. Isotopes can move from the water to the sediments or to the biota. In effect the sediments and biota compete for the isotopes in the water. Even though in some instances sediments are initially successful in removing large quantities of radionuclides from the water and thus preventing their immediate uptake by the biota, this sediment-associated radioactivity may later affect many benthic species by exposing them to high levels of radiation. Also, any radioactivity leached from the sediments back to the water again becomes available for uptake by the biota. Even before the radioactivity is leached from the sediment it may become available to the biota, due to a variation in the strength of the bonds between the different radionuclides and the sediment particles. Loosely bound radionuclides can be "stripped" from particles of sediment and utilized by bottom-feeding organisms.

Radioactivity can be accumulated by an organism from either food or water or from both these sources simultaneously (Figure 3). Whether the radioactivity will be distributed throughout the tissues of an organism depends to a large extent upon the physical state of the radioisotope. If the isotope is particulate in form it may enter the digestive tract of certain animals while stuck to the outside of food organisms and subsequently may be eliminated from the animals' body without having been metabolized, since particles have difficulty passing through biological membranes. However, if the radioisotope occurs in the ionic state it

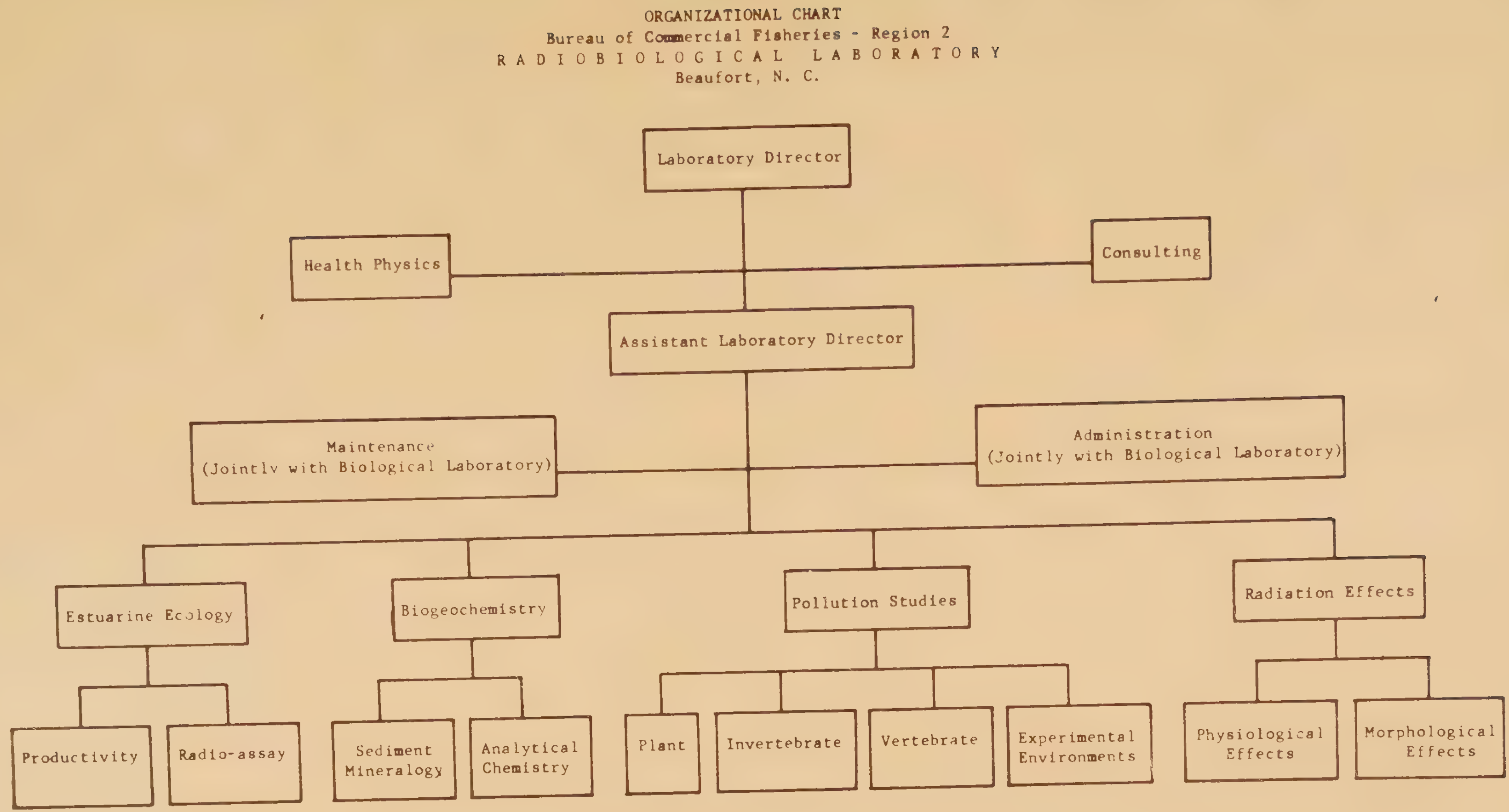


Figure 1. Organizational structure of the Bureau of Commercial Fisheries Radiobiological Laboratory.

Laboratory	Experimental Environment (Tanks and Ponds)	Natural Environment (Estuaries)
Control over Experimental Conditions	Partial Control over Experimental Conditions	Very Little Control over Experimental Conditions
Single species experiments	Several species - community approach	Natural communities or restricted communities
Confined volumes of water	Large volumes of water or flowing water	Tremendous volumes of water
Sacrificed animals for radioactive measurements	Radioactive measurements on entire animal - not sacrificed	Entire animal used for radioactive measurements
Can test effects of one factor at a time	Three components - water, biota, and sediments	Three components - water, biota, and sediments

Table 1. Three approaches used in the collection of data to predict the fate of radionuclides in the marine environment.

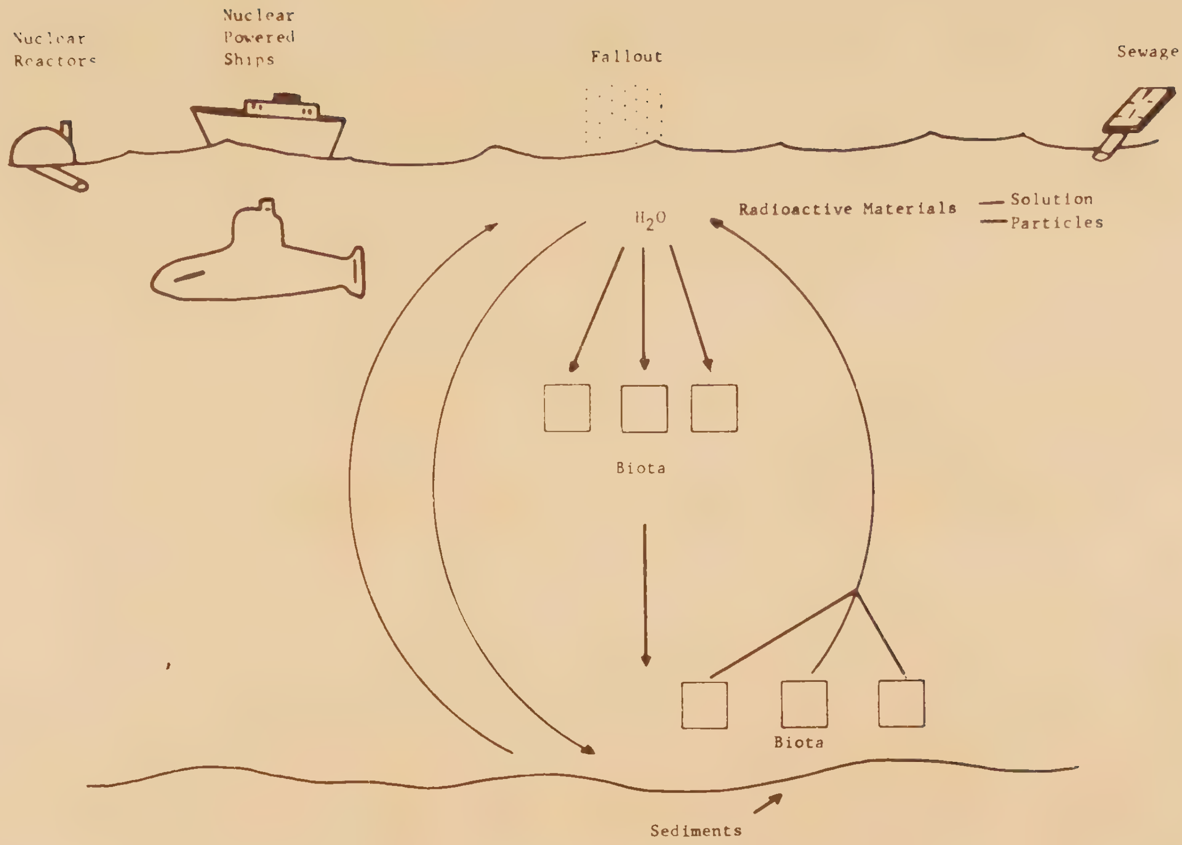


Figure 2. Sources of radioactive pollution and the cycling of radioisotopes in the marine environment.

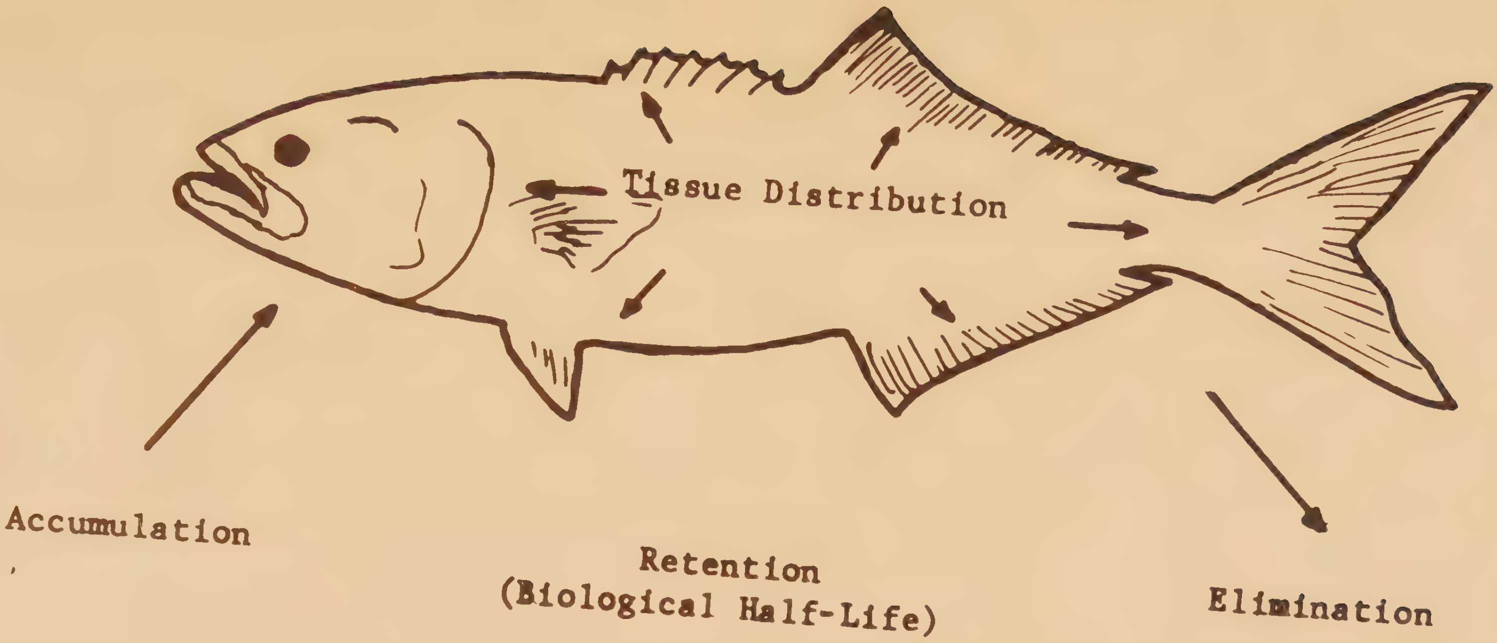


Figure 3. Schematic representation of the passage of radioactive materials through a fish.

can enter the tissues of an organism because of metabolic requirements or as a result of other factors. The time between the accumulation of a radioisotope and its elimination is the retention time or frequently is referred to as biological half-life, which is the length of time required for one-half of the radioactivity to be lost from the body of an organism.

There is a widespread belief that the retention curve for radioactivity in marine organisms is an exact reverse of the accumulation curve. However, we have collected data which proves that this is not always correct. The accumulation of zinc-65 from food by post-larval flounders, Paralichthys sp., and its retention when the fish were transferred to non-labeled running sea water was followed (Figure 4). The difference in the two rates is obvious. Of the zinc-65 accumulated during 91 days the fish were fed, only about 35 percent would have been lost from the fish if they had been kept in running sea water for 89 days. It is obvious from this curve that the loss of zinc-65 occurs at a slower rate than the rate of accumulation.

From the chemical composition of an organism it is possible to calculate the total amount of a radioisotope that will occur in the organism at a state of equilibrium in a given situation. However, from this data it is not possible to calculate the rate at which the radioisotope will be accumulated. Also, there is no particular reason to suspect that an organism concentrating an element to the highest level will have the fastest rate of accumulation. In one experiment in which the uptake of zinc-65 by a community of organisms was followed, it was found that, although fish contained more stable zinc than clams and crabs, the fish accumulated less radioactive zinc than either of these two organisms (Figure 5).

The Effect of Radiation on Marine Organisms

More complete and accurate information on the sensitivities of marine organisms to ionizing radiation is needed in order to predict and evaluate results occurring from radioactive contamination. The limited amount of data on the effects of radiation on marine organisms now available deals mostly with levels of radiation necessary to cause death or to severely alter the normal embryology and development of these organisms. One of the most probable effects of sublethal ionizing radiation is a change in the genetic material. With the new facilities of the Radiobiological Laboratory a knowledge of radiation effects may be used to increase production of the marine environment since all mutations from radiation are not necessarily deterimental. With the use of radiation and controlled breeding experiments, larger, faster growing, more resistant strains of commercially important species may be produced. Also, controlled irradiation may prove to be useful in eradication of undesirable species through sterilization or mutation.

Radioactive Tracer Techniques in Fishery Biology

Many new research possibilities have arisen in the field of fishery biology as radioactive materials have become available. The great sensitivity in the measurement of radioactivity has made possible the application of tracers to problems beyond the range of standard methods. Radioisotopes have been used in fishery biology to (1) measure primary productivity, (2) determine feeding habits and rates and the extent to which "food" is utilized, (3) follow physiological processes, (4) determine the cycling of nutrients, (5) label or mark marine organisms, and (6) trace sediment and water movement. Only a few examples pertaining to foods and feeding will be discussed in this paper.

It is now known that the accumulation of most radioisotopes by marine animals occurs at a faster rate from food than from water. Also, it has been assumed that regardless of whether the radioisotope is accumulated from food or water the level of activity in the animal eventually will reach the same level. A hypothetical consideration of the accumulation of a radioisotope from food and water is shown in Figure 6. Using the brine shrimp, Artemia salina, we have found that zinc-65 not only is accumulated faster from food than from water, but that the animals will never accumulate as much zinc-65 from water as from food, since they do not live long enough (Figure 7). Since Artemia live for four to six months under laboratory conditions, it can be seen that the line representing the accumulation of zinc-65 from water, if extended to six months, would not reach as high a level as the line representing the accumulation of zinc-65 from food.

Whether or not an organism is a satisfactory food is very difficult to determine without the use of radioactive tracers. However, with a radioisotope the food need only be labeled and then consumed by an animal. If digestion and utilization of the ingested food occurs, a positive correlation will be obtained between the amount of food passing through the intestinal tract and the amount of nutrient material assimilated by the tissues of the animal. Conversely, the lack of a correlation will suggest that no utilization of this ingested material occurs. Oysters were fed Carteria, Skeletonema, Chlamydomonas, and Chlorella labeled with radioactive phosphorus. A good correlation was found between the number of radioactive alga cells, and therefore the phosphorus-32, in the digestive tract of the oyster, and the radioactive phosphorus of the adductor muscle when oysters fed on Carteria, Skeletonema, and Chlamydomonas cells. However, there was no correlation when oysters fed on Chlorella (Figure 8). Even though there were more radioactive Chlorella cells passing through the intestinal tract of some oysters, there was no additional accumulation of phosphorus-32 in the adductor muscle. The adductor muscle was used for this test, since it was believed that phosphorus-32 could get into this tissue only from metabolic processes.

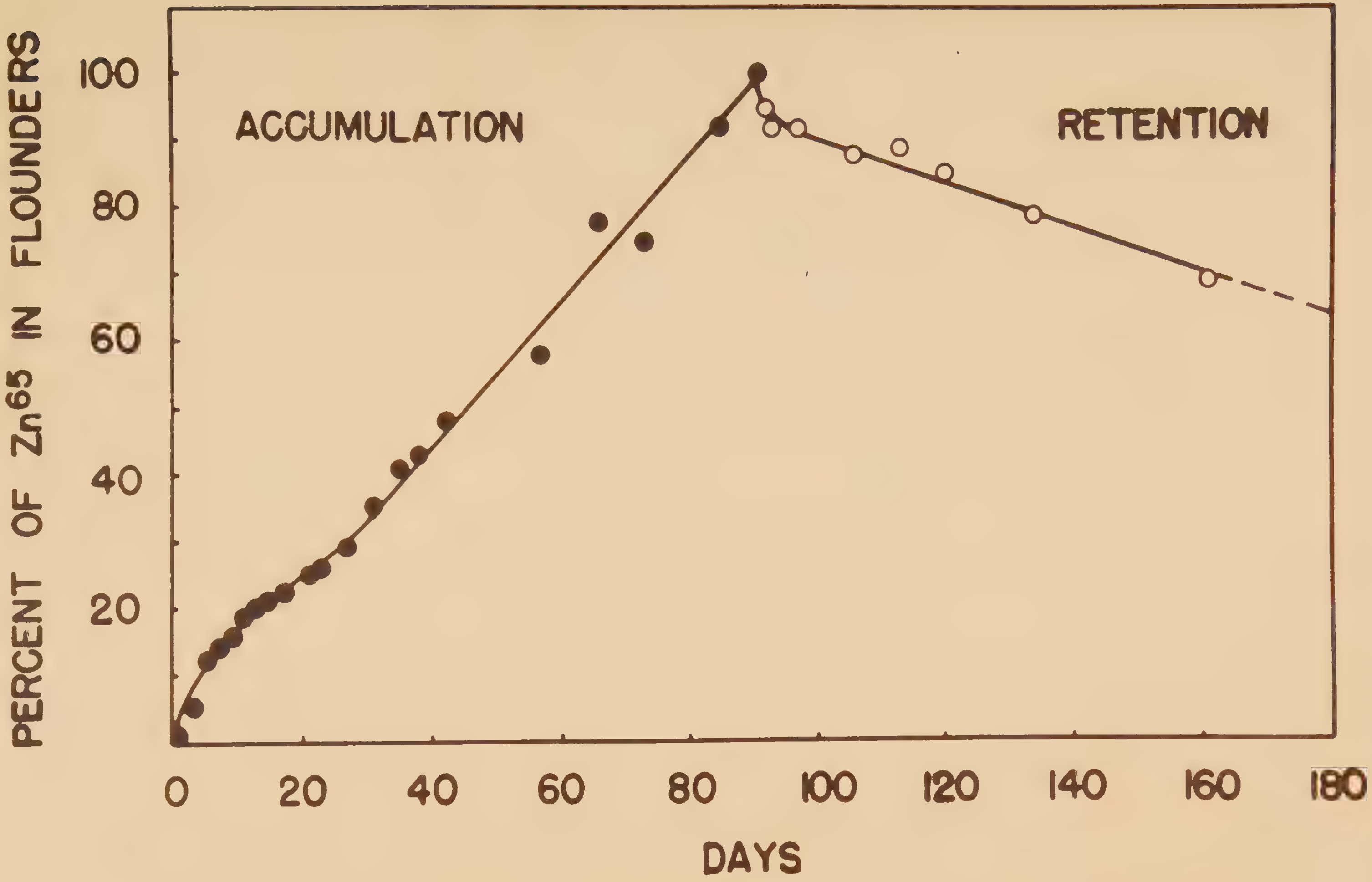


Figure 4. Accumulation and retention of zinc -65 by post-larval flounders. The zinc-65 accumulated after 91 days equals 100 percent.

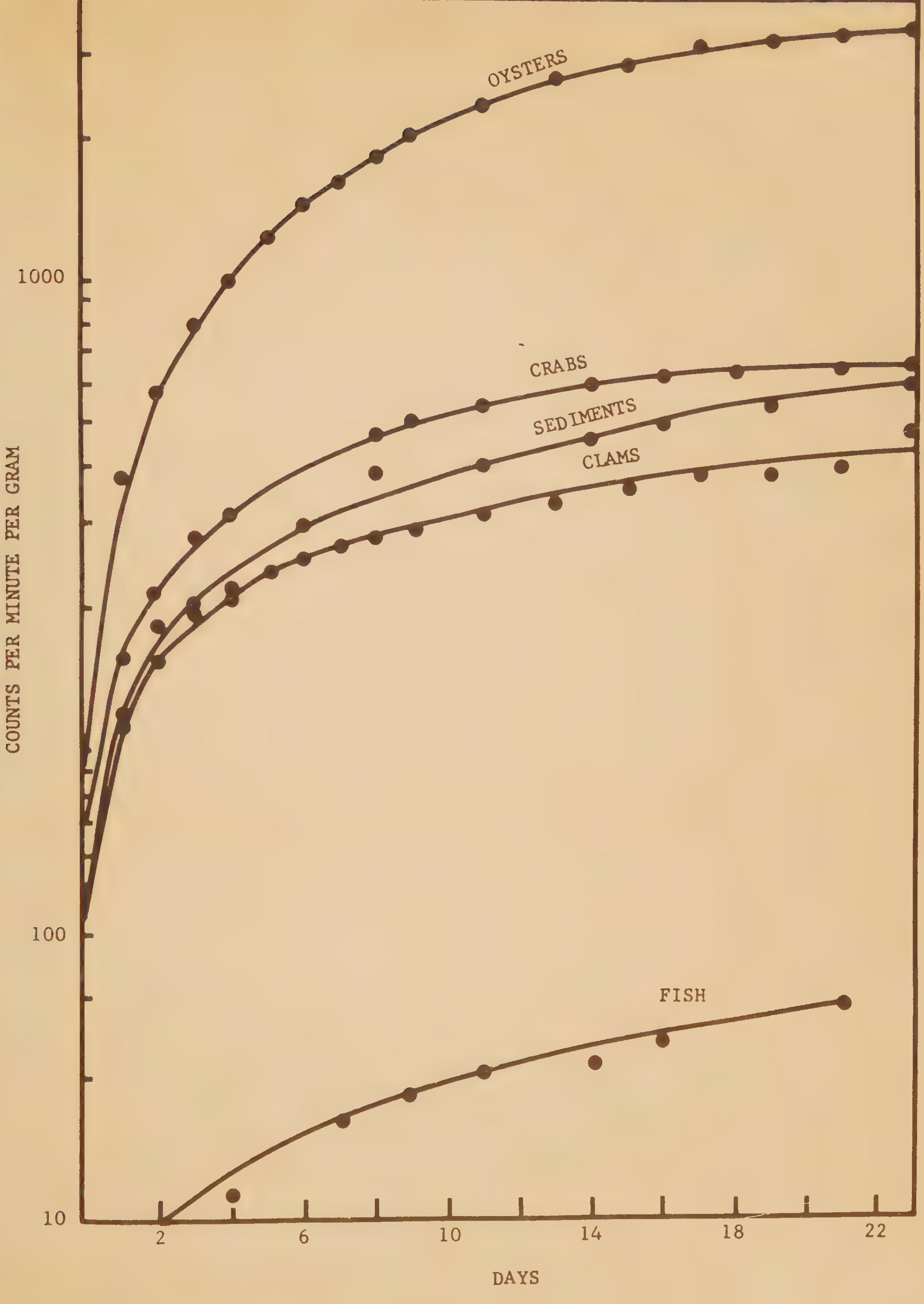


Figure 5. Uptake of zinc -65 in an experimental environment.

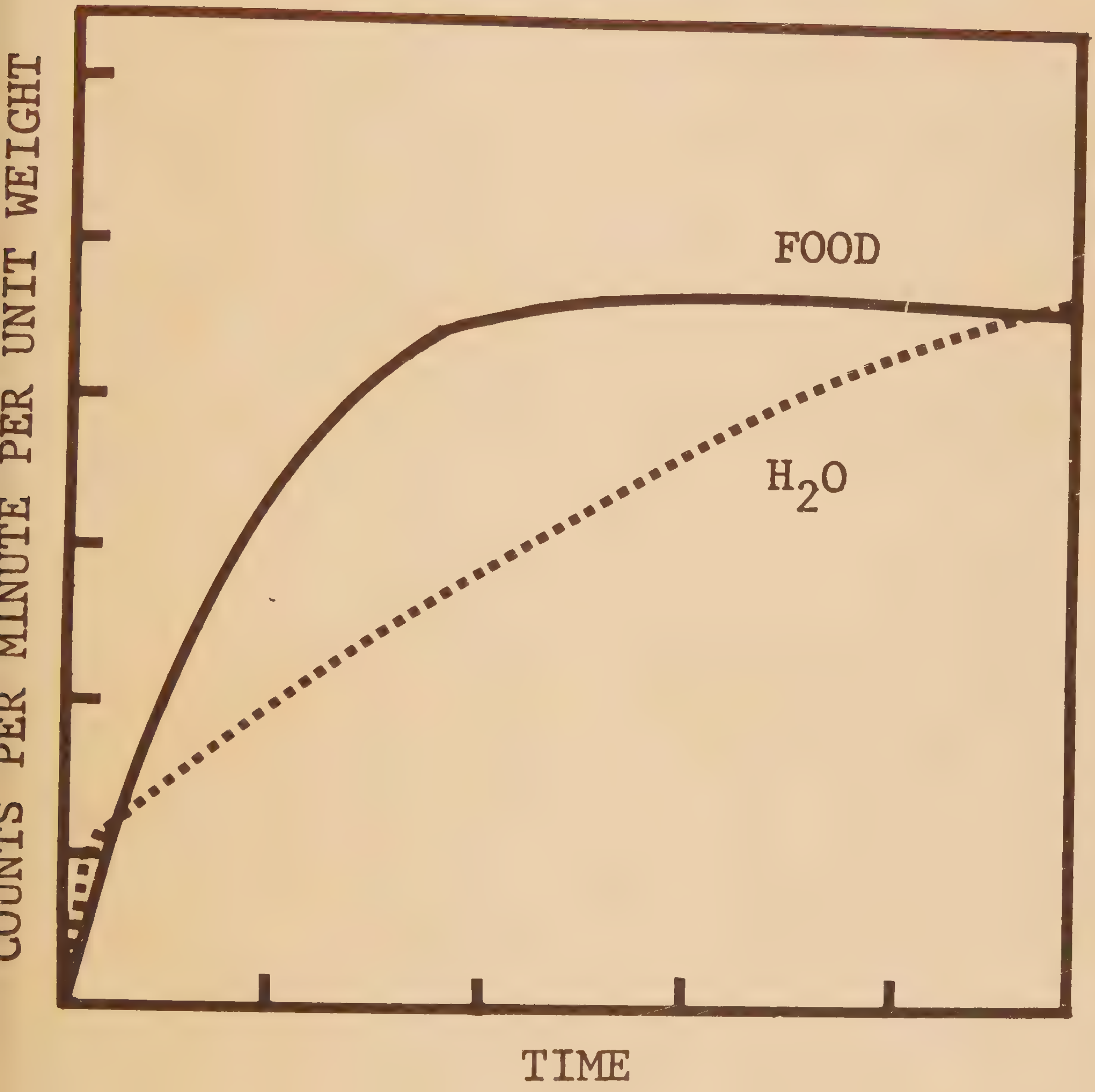


Figure 6. Hypothetical consideration of the accumulation of a radioisotope by a marine animal from food and water.

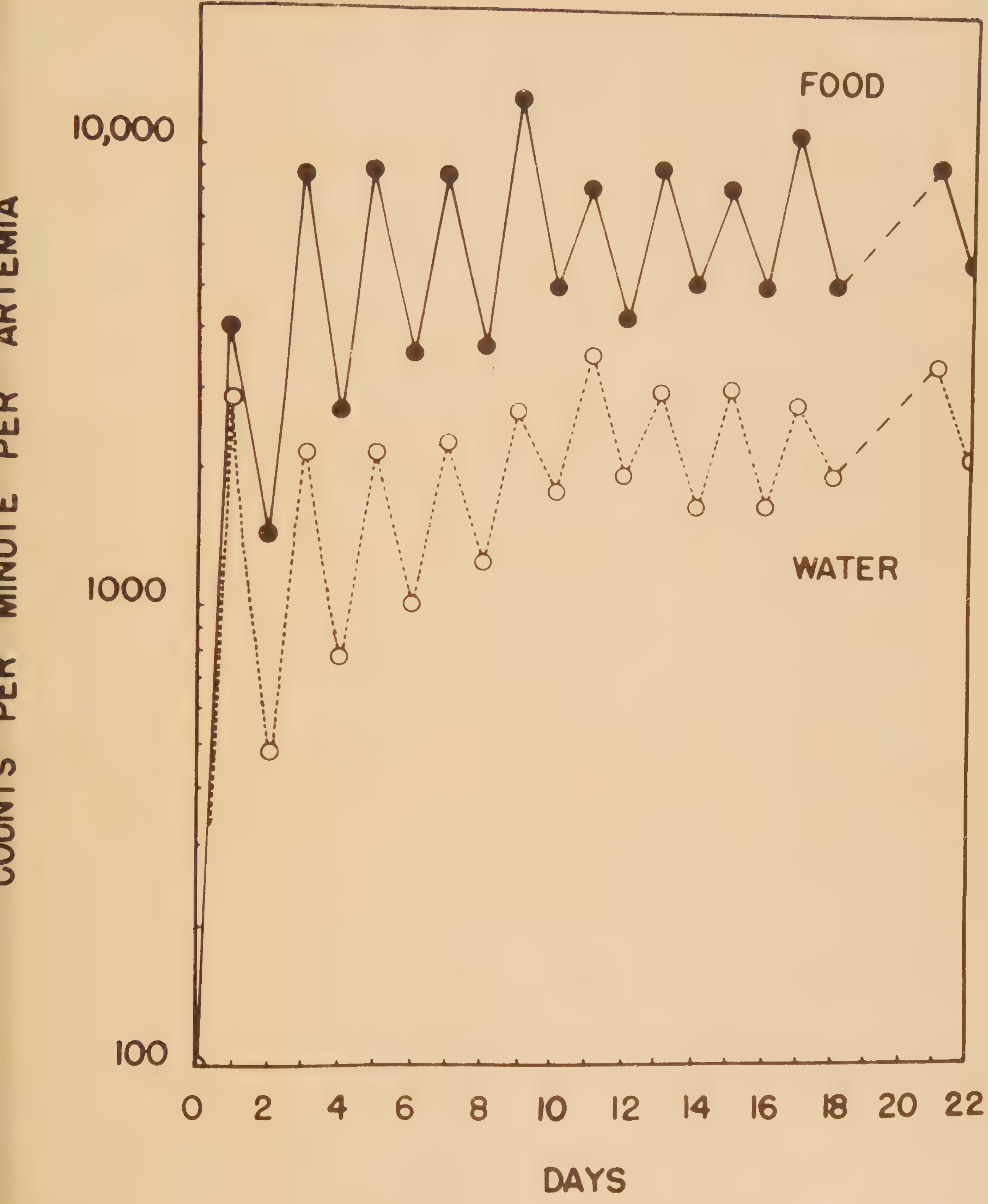


Figure 7. Comparison of accumulation of radioactive zinc by Artemia from food and water.

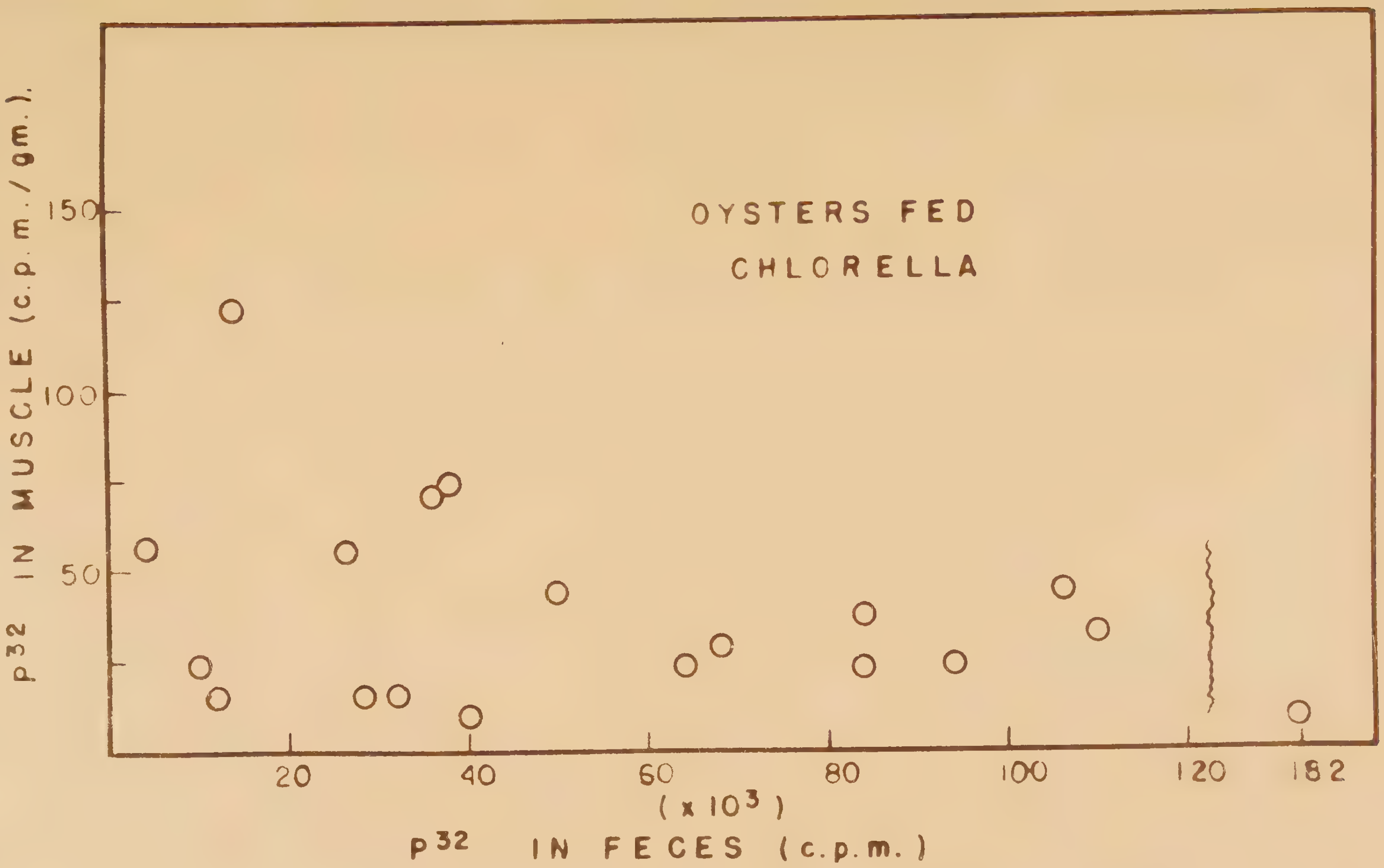


Figure 8. Failure of oysters to utilize Chlorella cells as shown by the lack of correlation between phosphorus-32 in the adductor muscle and that passing through the digestive tract.

Summary

The greatest concern of those who oppose the disposal of radioactive waste or the release of radioactive materials from nuclear reactors into the oceans is the possibility of its return to man in sea food. It may appear logical to conclude that the extent to which these organisms are hazardous to man depends upon the amount of radioactivity concentrated in the edible tissues. However, even though radioactive particles cannot easily pass through living membranes of larger animals, they can be accumulated in their digestive tract. If the animal is a filter-feeding animal such as the oyster, particulate radioisotopes in the digestive tract will be passed on to man just as readily as soluble radioisotopes contained in the tissues, since all of the soft tissues of the oyster are eaten. It is obvious, that there is need for additional research on the cycling of radioactivity in the marine environment with emphasis on its possible return to man.

The fishing industry will continue to profit from research involving radioisotope tracer techniques. Already, the great sensitivity in the determination of radioactivity has made possible the application of tracers to fishery problems beyond the range of standard methods. As instrumentation and a knowledge of these techniques advance, biologists will be able to expand research in such a manner that both the quality and quantity of fishery products will be improved.

11

SYSTEMATIC STUDIES OF DARTERS FROM SOUTHEASTERN UNITED STATES (PISCES, PERCIDAE).

William Joseph Richards, Ph.D.
Cornell University, 1963

Reprinted from DISSERTATION ABSTRACTS
Volume XXIV, No. 9, 1964

SYSTEMATIC STUDIES OF DARTERS FROM SOUTHEASTERN UNITED STATES (PISCES, PERCIDAE).

(Order No. 64-3654)

William Joseph Richards, Ph.D.
Cornell University, 1963

Part I. Description of a new percid fish, with a study of the subgenus *Hadropterus*.

A new species of *Percina* from the Alabama River System is described and compared with *P. nigrofasciata* and *P. sciera*, the other two members of the subgenus *Hadropterus*. This new species has a distinctive color pattern and small scales (lateral line scales 77-90). The nomenclatural history of *Hadropterus* is reviewed and this subgenus is diagnosed and redescribed.

Part II. Systematics of the percid fishes of the subgenus *Oligocephalus* (Genus *Etheostoma*) from the Atlantic drainages in Georgia and the Carolinas.

Etheostoma fricksium, *E. mariae*, *E. parvipinne* and *E. hopkinsi* (subgenus *Oligocephalus*) are found in Atlantic drainages in Georgia and the Carolinas. The first three form a natural species group in this subgenus while *E. hopkinsi*, though confused in the past with *E. fricksium*, is easily separable. Specific and infraspecific variation of morphological characters is investigated in *E. fricksium*, *E. mariae* and *E. parvipinne*. *E. mariae*, which is confined to a small geographic area, exhibits little variation. *E. fricksium* shows slight variation while the wide ranging *E. parvipinne* is very variable.

Part III. Systematics of the percid fishes of the *Etheostoma thalassinum* species group with comments on the subgenus *Etheostoma*.

Etheostoma thalassinum from the Santee River System and *E. inscriptum* from the Altamaha, Savannah and Edisto river systems are shown to be closely related species.

The third representative of this group, *E. swannanoa* from the headwaters of the Tennessee River System, exhibits several specialized features. These include absence of palatine teeth, reduction in number of prevomerine teeth, and presence of a basal orange-red band in the spinous dorsal fin. These features among others relate this group to the *E. blennioides* group.

Sexual and temporal variation is studied in several large series of *E. inscriptum*. Only fin rays differed significantly in the sexes.

The subgenus *Etheostoma* is diagnosed and relationships of the species within this subgenus is discussed.

Microfilm $2.75; Xerography $8.80. 195 pages.

A microfilm or xerographic copy of the complete manuscript i available from the publisher, University Microfilms, Inc. Ann Arbor, Michigan, at the prices quoted at the end of th abstract.

Made in United States of America
Reprinted from Copeia, 1964, No. 4, December 31
pp. 690–701

Percina lenticula, a New Percid Fish, with a Redescription of the Subgenus *Hadropterus*

William J. Richards and Leslie W. Knapp

Percina lenticula, a New Percid Fish, with a Redescription of the Subgenus *Hadropterus*[1]

William J. Richards and Leslie W. Knapp[2]

A new species of *Percina* from the Alabama River system is described and compared with *P. nigrofasciata* and *P. sciera,* the other 2 members of the subgenus *Hadropterus.* The new species has a distinctive color pattern and small scales (lateral line scales 77–90). The nomenclatural history of *Hadropterus* is reviewed and this subgenus is diagnosed and redescribed.

THE discovery of *Percina lenticula,* a distinctive new species from the Alabama River basin, brings to 3 the number of species in the subgenus *Hadropterus.* In addition to describing the new species, it seems desirable here to diagnose and redescribe the subgenus and to review its nomenclatural history. The monotypic genus *Hadropterus* was erected by Agassiz (1854) when he described *H. nigrofasciatus* from near Mobile, Alabama. Since that time, *Hadropterus* has been used variously as a genus or subgenus and has included a fluctuating number of species. The species and subspecies (including valid and nominal forms) which have been assigned to the genus or subgenus *Hadropterus* are listed in Table 1. Jordan and Gilbert (1883) added *Cottogaster aurantiaca* Cope to the genus *Hadropterus.* Jordan and Evermann (1896) included 4 subgenera (*Alvordius, Hadropterus, Serraria,* and *Ericosma*) and 12 forms in the genus *Hadropterus.* Jordan, Evermann, and Clark (1930) regarded *Hadropterus* as being monotypic. Bailey (1951) directly or inferentially placed 8 generic names under the genus *Hadropterus* and later synonymized (Bailey, Winn, and Smith 1954) *Hadropterus* under *Percina.* Subsequently, Bailey (Bailey and Gosline 1955) designated 7 of the genera as subgenera and included *Percina nigrofasciata* and *P. sciera* in the subgenus *Hadropterus.* We agree with this grouping and add *P. lenticula* to *Hadropterus.* We provisionally visualize *Hadropterus* as including the following forms: *Percina nigrofasciata nigrofasciata* (Agassiz), from the Mississippi River system, Louisiana, to the Edisto River system, South Carolina, southward into peninsular Florida, throughout the St. Johns and Suwannee river systems; *P. nigrofasciata raneyi* Crawford, from the Savannah River system above the fall line in Georgia and South Carolina; *P. sciera sciera* (Swain), from the eastern tributaries of the Mississippi River system and along the Gulf coast east to the Pearl River in Mississippi; *P. sciera apristis* (Hubbs and Hubbs), from the San Marcos, Comal, and Guadalupe rivers of the Guadalupe River system in Texas; and *P. lenticula,* new species, from the Alabama River system in Alabama and Georgia. Pending further study, populations of *P. sciera* from west of the Mississippi River in Missouri, Arkansas, Oklahoma, and Texas are not assigned subspecific status.

Subgenus *Hadropterus* Agassiz

Hadropterus Agassiz 1854:305. Type species, *Hadropterus nigrofasciatus* Agassiz, by monotypy.

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[1] This contribution is parts of dissertations for the degree of Doctor of Philosophy submitted to the Graduate Faculty of Cornell University by the authors.

[2] Present addresses: William J. Richards, Bureau of Commercial Fisheries, Biological Laboratory, Building 74, Navy Yard Annex, Washington, D. C. 20390; Leslie W. Knapp, Oceanographic Sorting Center, Smithsonian Institution, Washington 25, D. C.

TABLE 1. FORMS THAT HAVE BEEN INCLUDED IN THE GENUS GROUP *Hadropterus.*

Original Name	Authority First Using *Hadropterus*	Present Name
Hadropterus nigrofasciatus Agassiz	Agassiz 1854	*P.* (*Hadropterus*) *nigrofasciata*
Hadropterus maculatus Girard	Girard 1859	*P.* (*Alvordius*) *notogramma*
Hadropterus shumardi Girard	Girard 1859	*P.* (*Imostoma*) *shumardi*
Hadropterus tessellatus Jordan	Jordan 1877	*E.* (*Etheostoma*) *variatum*
Cottogaster aurantiacus Cope	Jordan 1877	*P.* (*Hypohomus*) *aurantiaca*
Hadropterus scierus Swain	Swain 1884	*P.* (*Hadropterus*) *sciera*
Etheostoma macrocephalum Cope	Jordan 1885	*P.* (*Alvordius*) *macrocephala*
Etheostoma phoxocephalum Nelson	Jordan 1885	*P.* (*Swainia*) *phoxocephala*
Alvordius aspro Cope and Jordan	Jordan 1885	*P.* (*Alvordius*) *maculata*
Etheostoma (*Hadropterus*) *ouachitae* Jordan and Gilbert	Jordan and Gilbert 1886	*P.* (*Imostoma*) *uranidea*
Etheostoma peltatum Stauffer	Jordan 1885	*P.* (*Alvordius*) *peltata*
Alvordius evides Jordan and Copeland	Jordan 1885	*P.* (*Ericosma*) *evides*
Diplesion fasciatus Girard	Jordan 1885	*E.* (*Austroperca*) *australe*
Etheostoma (*Hadropterus*) *squamatus* Gilbert and Swain	Gilbert and Swain *in* Gilbert 1887	*P.* (*Swainia*) *squamata*
Etheostoma (*Hadropterus*) *cymatotaenia* Gilbert and Meek	Gilbert and Meek *in* Gilbert 1887	*P.* (*Hypohomus*) *cymatotaenia*
Etheostoma (*Hadropterus*) *nianguae* Gilbert and Meek	Gilbert and Meek *in* Gilbert 1887	*E.* (*Oligocephalus*) *nianguae*
Etheostoma variata Kirtland	Jordan 1885	*E.* (*Etheostoma*) *variatum*
Etheostoma tessellata Storer	Jordan 1885	*P.* (*Ericosma*) *evides* ??
Etheostoma cinerea Storer	Jordan 1885	*E.* (*Allohistium*) *cinereum*
Hadopterus scierus serrula Jordan and Gilbert	Jordan and Gilbert 1886	*P.* (*Hadropterus*) *sciera*
Hadropterus roanoka Jordan and Jenkins	Jordan and Jenkins *in* Jordan 1889	*P.* (*Alvordius*) *crassa*
Alvordius maculatus Girard	Jordan and Evermann 1896	*P.* (*Alvordius*) *maculata*
Etheostoma güntheri Eigenmann and Eigenmann	Jordan and Evermann 1896	*P.* (*Imostoma*) *shumardi*
Hadropterus maxinkuckiensis Evermann	Evermann 1900	*P.* (*Alvordius*) *maculata*
Hadropterus evermanni Moenkhaus	Moenkhaus 1903	*P. caprodes* × *P. maculata*
Hadropterus sellaris Radcliffe and Welsh	Radcliffe and Welsh 1913	*E.* (*Etheostoma*) *sellare*
Hadropterus oxyrhynchus Hubbs and Raney	Hubbs and Raney 1939	*P.* (*Swainia*) *oxyrhyncha*
Hadropterus palmaris Bailey	Bailey 1940	*P.* (*Ericosma*) *palmaris*
Hadropterus nasutus Bailey	Bailey 1941	*P.* (*Swainia*) *nasuta*
Hadropterus nigrofasciatus westfalli Fowler	Fowler 1945	*P.* (*Hadropterus*) *n. nigrofasciata*
Hadropterus notogrammus Raney and Hubbs	Raney and Hubbs 1948	*P.* (*Alvordius*) *notogramma*
Hadropterus scierus apristis Hubbs and Hubbs	Hubbs and Hubbs *in* Hubbs 1954	*P.* (*Hadropterus*) *sciera apristis*
Hadropterus pantherinus Moore and Reeves	Moore and Reeves 1955	*P.* (*Alvordius*) *pantherina*
Percina nigrofasciata raneyi Crawford	Crawford 1956	*P.* (*Hadropterus*) *nigrofasciata raneyi*

TABLE 2. NUMBER OF LATERAL LINE SCALES FOR THE SPECIES OF *Percina* (SUBGENUS *Hadropterus*). Holotype in boldface.

Species	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	*N*	$\bar{x}$
n. nigrofasciata[1]	3	3	6	18	60	89	128	144	182	212	190	195	139	121	66	55	36	13	2	4	1	–	–	–	–	–	–	–	–	1,667	55.8
n. raneyi[1]	–	–	–	–	–	–	–	–	–	1	1	3	2	2	10	9	14	12	10	16	6	4	3	3	–	3	–	–	–	99	63.2
s. sciera[2]	–	–	–	–	–	–	–	–	–	–	1	4	4	11	12	18	18	16	16	19	12	9	10	7	3	2	–	–	–	162	63.4
s. apristis[2, 3]	–	–	–	–	–	–	–	-	–	–	–	–	–	–	–	–	–	2	3	7	7	9	7	6	8	4	2	4	2	61	68.1

Species	77	78	79	80	81	82	83	84	85	86	87	88	89	90	*N*	$\bar{x}$
lenticula (total)	2	1	–	2	2	1	1	**3**	1	2	–	–	2	1	18	82.9
Cahaba R.	2	1	–	2	2	1	–	**2**	–	–	–	–	–	–	10	80.4
Etowah R.	–	–	–	–	–	–	1	1	1	2	–	–	2	1	8	86.5

[1] Data from Crawford (1956).

[2] Data in part from Hubbs and Black (1954).

[3] Clark Hubbs (1954) gave range in lateral line scales as 63 to 78 ($\bar{x} = 69$).

Plesioperca Vaillant 1873:36. Type species, *Plesioperca anceps* Vaillant (= *P. nigrofasciata*), by monotypy.

Serraria Gilbert 1884:205. Type species, *Hadropterus scierus* Swain, by original designation.

Diagnosis.—A subgenus of the genus *Percina* with moderate to small scales (lateral line 46–90, Tables 2 and 3); premaxillary frenum present; branchiostegal membranes moderately conjoined; snout moderately long and pointed, not projecting beyond upper jaw; caudal base with a vertical row of 3 dark spots (lower 2 frequently fused with last body blotch to form its posterior border); spinous dorsal without submarginal orange band; no lateral tessellated markings; broad vertical bars if present, not joined across back with those of opposite side; anal fin of adult male not excessively elevated. As in other subgenera of *Percina* except *Imostoma, Percina,* and *Ericosma,* sexual dimorphism is little developed, and bright colors and breeding tubercles are lacking.

Description.—Lateral line straight and complete; lateral line extends onto caudal fin on 0 to 6 scales (Table 4); vertebrae 39 to 44 (Table 5); interorbital space neither broad nor depressed; branchiostegal rays 6-6; preopercle serrate or entire; (air) swim bladder rather large (but thin-walled) and well developed in young. Squamation: cheek with embedded ctenoid scales, sometimes naked on the lower half; opercle and nape covered with ctenoid scales; breast usually naked in females, but with 1 or more enlarged, ctenoid scales between the pelvic bases, males often with several enlarged ctenoid scales on the midline of the breast and with embedded scales elsewhere; midline of belly in males, usually with moderately enlarged and strongly ctenoid scales, but females usually either naked or covered with ctenoid scales similar to the normal body scales. Fin rays: dorsal IX to XV (usually XI to XIII), 10 to 14; anal II, 7 to 10 (usually 9) (Table 6). Depressed pectoral fin reaches approximately to tip of pelvic fin in young (42.5 mm and smaller), but falls far short of pelvic tip in adult; anal fin of adult male does not extend beyond posterior end of depressed soft dorsal fin. Color pattern: a lateral series of about 7 to 17 dark bars or blotches, these range in shape from broad ovals to vertical bars which do

TABLE 3. SCALE COUNTS FOR THE SPECIES OF *Percina* (SUBGENUS *Hadropterus*). Holotype in boldface.

Species	Summation of Scales Above Plus Below the Lateral Line																							
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	*N*	$\bar{x}$
n. nigrofasciata[1]	2	11	61	245	416	415	293	119	35	6	–	–	–	–	–	–	–	–	–	–	–	–	1,603	15.7
n. raneyi[1]	–	–	–	1	1	2	10	13	35	25	7	4	–	–	–	–	–	–	–	–	–	–	98	19.0
s. sciera	–	–	–	–	–	3	6	10	9	5	4	3	1	–	–	–	–	–	–	–	–	–	41	18.9
s. apristis	–	–	–	–	–	–	–	1	–	–	2	4	4	10	2	2	–	–	–	–	–	–	25	23.3
lenticula (total)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	2	**3**	5	6	18	30.6
Cahaba R.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	2	**3**	1	2	10	29.9
Etowah R.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4	4	8	31.5

Species	Caudal Peduncle Scales																				
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	*N*	$\bar{x}$
n. nigrofasciata[1]	1	9	40	197	354	500	229	137	36	5	–	–	–	–	–	–	–	–	–	1,503	20.8
n. raneyi[1]	–	–	–	–	3	16	13	35	24	7	–	1	–	–	–	–	–	–	–	99	22.9
s. sciera	–	–	–	–	–	2	6	11	12	6	4	–	–	–	–	–	–	–	–	41	23.6
s. apristis	–	–	–	–	–	–	–	–	–	5	5	3	4	6	2	–	–	–	–	25	27.3
lenticula (total)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	3	4	**8**	2	18	32.4
Cahaba R.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	**6**	2	10	32.8
Etowah R.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	3	2	–	8	31.9

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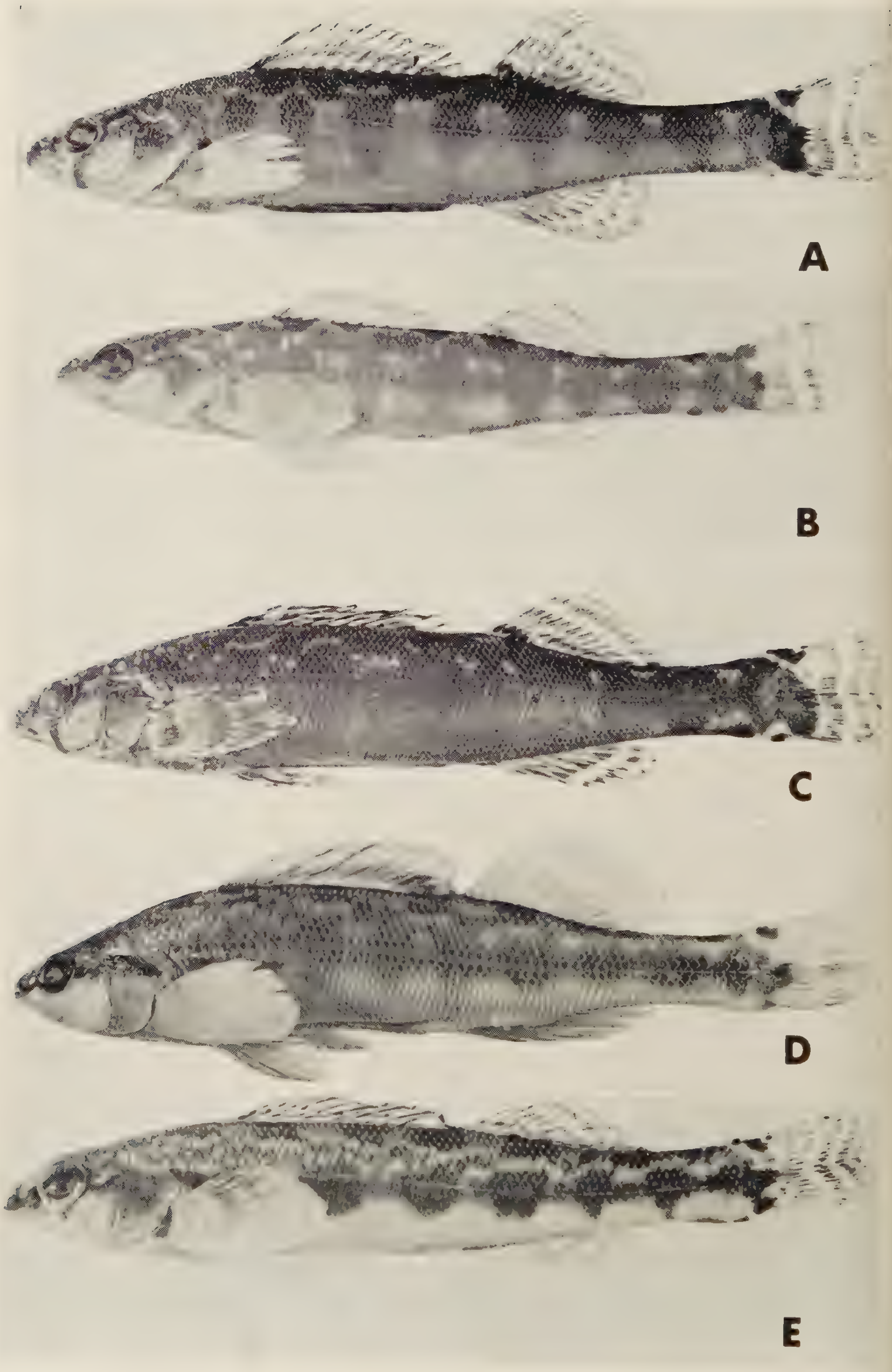
[1] Data from Crawford (1956).


A
B
C
D
E

not cross the back, but which occasionally reach to dorsal and ventral midlines on the posterior part of the body; subocular bar absent to well developed.

Percina lenticula, new species

Freckled Darter

(Fig. 1A–C)

This species seems to have been collected first by Dr. Clarence M. Tarzwell on 8 October 1950, when he was conducting a U. S. Public Health Service survey of the Allatoona impoundment area at the mouth of Canton Town Creek, Cherokee County, Georgia. A few years later, Dr. Donald C. Scott of the University of Georgia examined these specimens in the Public Health Service collections in Cincinnati, and, recognizing them as unusual, deposited them in the collection of the Department of Zoology at the University of Georgia. When studying darters in the University of Georgia collection, Richards noted the series of *Percina* and recognized them as an undescribed species.

Meanwhile, Dr. Royal D. Suttkus of Tulane University had collected eight specimens in the Cahaba River, Bibb County, Alabama, on 17 May 1957. Dr. Suttkus also recognized the uniqueness of the form and returned to this general locality on 9 July 1958 and 9 May 1959 to get additional specimens.

The authors are grateful for the opportunity to examine these specimens originally deposited in the collections of Georgia and Tulane universities, and wish to thank Drs. Scott and Suttkus for relinquishing their material and for making available ecological data. They also have kindly agreed to the deposition of the material as stated below.

Material.—Holotype, Cornell Univ. (CU) 43592 (♂, 96.4 mm SL), Ala., Bibb Co., Cahaba R. at Ala. Hwy. 27, 8.5 mi N of Centerville, Alabama R. drainage, 9 May 1959, RDS 2776, R. D. Suttkus and J. S. Suttkus

Paratypes: CU 43593 (♀, 95), Ala., Bibb Co., Cahaba R. at Ala. Hwy. 5, 2.2 mi N of Centerville, Alabama R. drainage, 8 July 1958, RDS 2736, R. D. Suttkus and party; Tulane Univ. 15291 (7 ♀, 77–92) and CU 43594 (♂, 86), same locality as CU 43593 on 17 May 1957, RDS 2594, by R. D. Suttkus, R. J. Miller, H. V. Miller, and J. de Abate; and Univ. Georgia 209 (3 ♂, 1 ♀, 48–63), CU 43435 (1 ♂, 1 ♀, 55–58), U. S. Natl. Mus. 197491 (♂, 64), and Univ. Mich. Mus. Zool. 180074 (♂, 60), Ga., Cherokee Co., Etowah R. at mouth of Canton Town Cr., Alabama drainage, 8 October 1950, C. M. Tarzwell.

The methods described by Hubbs and Lagler (1958) were followed in taking all counts and measurements except for those defined below.

Pored scales on the caudal fin are enumerated as follows: cases where the lateral line canal does not extend onto the caudal base are counted as 0; when the lateral line canal does extend onto the caudal base, the first pored scale posterior to the hypural plate is counted as 1, the second pored scale is counted as 2, etc. *Body width* is the maximum width. *Length of caudal fin* is measured from the middle of the base of the fin to the tip of the longest ray when the fin is in a normal position. *Length of pelvic fin base* is the greatest overall basal length, extending from the structural base of the first ray to the point where the membrane behind the last ray joins the body. *Interpelvic space* is the greatest dimension between the structural bases of the first pelvic rays. *Lower jaw to juncture of branchiostegal membrane* is measured from the anteriormost tip of the lower jaw to the anteriormost edge of the branchiostegal membrane. *Pelvic insertion to juncture of branchiostegal membrane* is measured from the anterior structural base of the pelvic fin to the anteriormost edge of the branchiostegal membrane. Angle of muzzle is the angle formed by the lateral profile of the snout and lower jaw. *Angle of head* is the angle formed by the lateral profile of the head. *Angle of branchiostegal membrane* is the angle formed by the left and right branchiostegal membrane.

Diagnosis.—A species of the subgenus *Hadropterus* with very small scales (lateral line 77–90), a dark spot on the anterior base of the soft dorsal fin, 1 or 2 dark spots on the

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Fig. 1. Patterns of 3 forms of *Percina*. A: *Percina lenticula*, holotype CU 43592, male, 96.4 mm SL. B: *P. lenticula*, paratype CU 43435, male, 54.8 mm SL. C: *P. lenticula*, paratype CU 43593, female, 95.0 mm SL. D: *P. sciera sciera* (Swain), CU 42024, male, 77.1 mm SL. E: *P. sciera apristis* (Hubbs and Hubbs), CU 37399, female, 63.1 mm SL.

TABLE 4. NUMBER OF PORED SCALES ON THE CAUDAL FIN BASE IN THE SPECIES OF *Percina*.

Subgenus	Species	0	1	2	3	4	5	6	N	$\bar{x}$
Percina	*caprodes*	46	51	28	15	3	1	–	144	1.17
	rex	5	4	–	–	–	–	–	9	0.44
Hypohomus	*aurantiaca*	19	11	3	–	–	–	–	33	0.42
	cymatotaenia	9	1	–	–	–	–	–	10	0.10
Alvordius	*macrocephala*	21	1	–	–	–	–	–	22	0.05
	maculata	51	–	–	–	–	–	–	51	0.00
	notogramma	32	1	–	–	–	–	–	33	0.03
	peltata	49	16	–	–	–	–	–	65	0.25
	pantherina	9	–	–	–	–	–	–	9	0.00
Ericosma	*evides*	82	6	–	–	–	–	–	88	0.07
	crassa	46	1	–	–	–	–	–	47	0.02
	palmaris	18	5	–	–	–	–	–	23	0.22
Swainia	*squamata*	8	1	–	–	–	–	–	9	0.11
	phoxocephala	10	1	–	–	–	–	–	11	0.09
	oxyrhyncha	31	7	1	–	–	–	–	39	0.21
	nasuta	13	–	–	–	–	–	–	13	0.00
Imostoma	*uranidea*	38	6	–	–	–	–	–	44	0.14
	shumardi	33	13	–	–	–	–	–	46	0.28
Cottogaster	*copelandi*	73	5	–	1	–	–	–	79	0.10
Hadropterus	*nigrofasciata*	50	152	104	29	5	1	–	341	1.38
	sciera	13	26	42	14	1	–	–	96	1.63
	lenticula	–	–	2	3	12	–	1	18	3.72

pectoral fin base and a distinctive body color pattern (Fig. 1A–C). The subocular bar is faintly to well developed.

Description.—*Percina lenticula* is relatively terete, with the caudal peduncle slender (see Fig. 1A–C). Counts and measurements of the holotype and paratypes are given in Tables 2–7 except for the following: anal fin II, 9 (holotype, Cahaba 8, Etowah 6), II, 10 (Cahaba 1, Etowah 2); caudal rays 17 (holotype, Cahaba 8, Etowah 8), 18 (Cahaba 1); pectoral rays 14-14 (Cahaba 6, Etowah 5), 14-15 (Cahaba 1), 15-14 (holotype, Etowah 1), 15-15 (Cahaba 2, Etowah 2). The belly usually is fully scaled with 1 or 2 rows of slightly enlarged modified ctenoid scales along the midline in males. Partially embedded ctenoid scales cover the nape and opercle, whereas those on the cheek are almost fully embedded. There is a small cluster of embedded scales anterior to the junction of the supratemporal and lateral canals on the head. The breast is naked or variably scaled with at least 1 enlarged modified ctenoid scale usually present between the pelvic fins. The prepectoral area is either naked or covered with embedded ctenoid scales.

All cephalic canals are complete with 10 or 11 pores in the preoperculomandibular canal; 8 to 10 pores in the infraorbital canal; the coronal, anterior and posterior nasal, interorbital, and postorbital pores are present. The lateral canal has 5 pores and there usually are 3 or 4 pores in the supratemporal canal.

The branchiostegal membranes are moderately conjoined and the values for the ratio, distance from tip of lower jaw to juncture of gill membranes divided by distance from the junction to insertion of pelvic fins are: holotype 0.87, paratypes 0.87–1.05 ($\bar{x} = 0.94$). The ratio of pelvic interspace divided by pelvic base, yields the following

TABLE 5. NUMBER OF VERTEBRAE IN THE SPECIES OF *Percina* (SUBGENUS *Hadropterus*). Holotype in boldface.

	39	40	41	42	43	44	N	$\bar{x}$
n. nigrofasciata[1]	1	11	7	–	–	–	19	40.3
sciera[1]	–	2	13	3	–	–	18	41.1
lenticula (total)	–	–	–	1	**12**	4	17	43.2
Cahaba R.	–	–	–	1	**8**	–	9	42.9
Etowah R.	–	–	–	–	4	4	8	43.5

[1] Data from Bailey and Gosline (1955).

TABLE 6. NUMBER OF DORSAL RAYS IN THE SPECIES OF *Percina* (SUBGENUS *Hadropterus*). Holotype in boldface.

Species and Drainage	Dorsal Spines									Dorsal Soft Rays						
	9	10	11	12	13	14	15	N	$\bar{x}$	10	11	12	13	14	N	$\bar{x}$
n. nigrofasciata[1]	1	10	200	1,089	308	8	1	1,616	12.1	91	806	652	45	–	1,594	11.4
n. raneyi[1]	–	1	22	71	5	–	–	99	11.8	14	68	17	–	–	99	11.0
s. sciera	–	–	2	20	15	4	–	41	12.5	–	6	23	12	–	41	12.1
s. apristis	–	–	–	20	5	–	–	25	12.2	–	2	14	9	–	25	12.3
lenticula (total)	–	–	–	2	**14**	2	–	18	13.0	–	–	**4**	10	4	18	13.0
Cahaba R.	–	–	–	1	**8**	1	–	10	13.0	–	–	**4**	6	–	10	12.6
Etowah R.	–	–	–	1	6	1	–	8	13.0	–	–	–	4	4	8	13.5

[1] Data from Crawford (1956).

values: holotype 0.58, paratypes 0.53–0.82 ($\bar{x}$ = 0.67).

Coloration in alcohol.—The head is mottled above changing into a lighter color laterally and ventrally. A dark lateral band passes from the rear of the head through the eye and may encircle the snout. A dark bar angles from the eye toward the occiput. A subocular bar is faintly to well developed. The chin is either stippled with scattered melanophores or has a dark blotch anteriorly. Scattered melanophores are located on the jaw below the angle of the gape, on the gular region, cheek, and opercle. The breast is light, but stippled with melanophores, while several dark blotches run along the midline from the pelvic bases to the center of the breast. Additional dark blotches are located on the axilla of the pelvic fins and the prepectoral area.

The body has 8 dark dorsal blotches which usually are regular in shape. The dorsum is marbled due to the pattern created by interconnecting dark blotches and narrow light interspaces. There are about 8 dark lateral blotches that may be connected by intermediate bars to form a lateral band. These blotches are vertically elongate and in some cases may encircle the body posterior to the anal fin origin (Fig. 1A–C). One or 2 lateral blotches below the soft dorsal fin usually fuse with adjacent dorsal blotches while the remaining lateral blotches are separated by a wavy light interspace from the adjacent dorsal blotches. Secondary dark blotches may be present on the lower part of the side and ventrally on the caudal peduncle. The belly is light, except for a dark streak usually visible along the midline.

On the anterior base of the soft dorsal fin, a series of interradial dark spots widens anteriorly to form a triangular blotch. Melanophores are concentrated on the edges of the rays to form 2 or 3 dark bands on the remainder of the fin. The spinous dorsal has 3 bands, 1 near the edge, another somewhat below the middle, and a third made up of interradial dark spots near the base. The anal fin also has 2 or 3 dark bands. The paired fins are light with faint dark spots forming 2 or 3 indistinct bands. In addition, the base of the pectoral fin has a dark bar or 1 or 2 round spots (Fig. 1A–C).

Three prominent dark spots on the caudal fin base usually connect by dark streaks with the posterior lateral blotch on the caudal peduncle. The upper spot is discrete and outlined by light whereas the median and ventral spots are fused. The caudal fin has 2 or 3 dark wavy vertical bands. The anterior band often merges above and below with the basicaudal spots, thus enclosing 2 light areas. The second dark band appears a little behind the point of branching of the caudal rays, whereas the third band, when present, is on the fin margin. The dark bands on all fins are formed primarily by melanophores concentrated laterally along the edges of the rays.

One of the Cahaba River specimens is an unusually melanistic female (Fig. 1B). Since there is little sexual dimorphism in color pattern, no normally pigmented female is illustrated.

Variation.—Because of the small sample and unequal representation of sexes, little can be inferred from the meristic and morphometric data as to sexual differences in *Percina lenticula*. Geographic variation exists between the populations from the Etowah River and the Cahaba River. The Etowah specimens are smaller, probably younger,

TABLE 7. MEASUREMENTS OF *Percina lenticula* EXPRESSED AS THOUSANDTHS OF STANDARD LENGTH.

	Holotype Cahaba	Paratypes Cahaba		Paratypes Etowah	
Number and Standard Length (mm)	1 (96.4)	9 (76.6–95.0)		8 (47.6–63.5)	
		$\bar{x}$	Range	$\bar{x}$	Range
Body depth	185	185	166–196	178	168–198
Body width	137	131	117–157	124	116–131
Caudal peduncle depth	91	87	83–91	83	81–85
Caudal peduncle length	241	239	236–258	261	256–265
Longest D. spine length	108	116	109–120	118	108–128
Longest D. soft ray length	139	142	138–149	138	136–141
First A. spine length	88	78	71–85	79	74–82
Longest A. ray length	151	156	148–166	155	144–168
Longest P_1 ray length	191	202	186–215	193	179–200
Caudal fin length	166	177	170–193	175	166–197
P_2 fin length	179	204	179–218	182	170–190
P_2 fin base length	48	49	45–53	36	33–42
Interpelvic space	28	28	24–34	26	25–28
Head length	232	244	239–250	258	248–270
Head width	136	132	121–151	133	127–146
Head depth	143	140	134–144	144	135–151
Snout length	56	61	58–65	67	65–70
Orbit length	53	56	51–59	65	60–71
Least fleshy interorbital width	54	54	51–59	58	55–60
Upper jaw length	58	65	57–69	70	65–74
Lower jaw to juncture of branchiostegal membrane	130	137	133–149	150	137–160
Pelvic insertion to juncture of branchiostegal membrane	149	145	141–151	162	153–169
Angle of muzzle	73°	67°	61°–76°	60°	56°–66°
Angle of head	45°	39°	34°–50°	52°	48°–56°
Angle of gill membranes	84°	86°	82°–90°	91°	85°–100°

than those from the Cahaba River, but attempts to estimate age from scales were unsuccessful. In most meristic characters (Tables 2, 3, and 4), the Etowah specimens have higher counts than those from the Cahaba. The best separation between the two populations is demonstrated by the difference in lateral line scales. Also, the Etowah population has 2 dark vertical bands on the caudal fin whereas the Cahaba fish have 3 bands (compare Fig. 1A and B with C). Study of additional specimens from intervening areas may determine whether the two populations merit nomenclatural recognition.

Etymology.—The Latin name *lenticula* is the feminine diminutive for freckle referring to the freckle-like dark blotches on the pectoral fin base.

Relationship.—Meristic characters (Tables 2 and 3) clearly indicate that *P. lenticula* is more closely allied with *P. sciera* than with *P. nigrofasciata*, and comparison of color patterns further substantiates this relationship. The lateral blotches of *P. lenticula* are more like those of *P. sciera* than those of *P. nigrofasciata*.

Although *P. lenticula* is an allopatric replacement for *P. sciera* in the Alabama drainage, it differs from the latter in many major characters. *P. lenticula* has more lateral line scales, more vertebrae, and more soft dorsal rays. Also, the number of pored scales on the caudal fin differs within the subgenus (Table 4). This character is useful in separating some subgenera, and we feel that a higher number of pored scales on the caudal base may be a primitive feature. The marbled pattern characteristic of *P. lenticula* is lacking in *P. sciera*. The dark blotches on the base of the pectoral fin and near the anterior base of the soft dorsal fin are unique to *P. lenticula*. The suborbital bar seen in *P. lenticula* usually is lacking in *P. s. sciera*.

. *s. apristis* and populations of *P. sciera* west f the Mississippi River usually have a sub- cular bar. *P. lenticula* is closer to *P. s. pristis* than to *P. s. sciera* in scale counts, ut this probably is due to convergence ather than to close relationship. It seems ikely that *P. lenticula* evolved in the Ala- ama River system from an ancestral stock vhich had reached the Alabama River hrough eastward migration from the Mis- issippi River system or else through stream apture from the Tennessee River. Since . *lenticula* apparently is a big river form, he first view seems the more credible. How- ver, physiographic evidence which supports he second view has been discussed by several vriters. Hayes and Campbell (1894) ad- anced the idea that a Tertiary Appalachian River connected the Coosa and Tennessee ivers of modern times. White (1904) not nly disputed this theory, but suggested that he present Conasauga River was formerly a ributary to the Tennessee River which had een captured by a stream in the Coosa rainage (Alabama River system). Satter- ield (1961, unpublished master's thesis, Uni- ersity of Georgia) proposed that the barbed atterns of several northeastward-flowing treams in the Etowah River system may epresent remnants of former tributaries of he Tennessee River and that the large num- er of species common to both the Alabama nd Tennessee drainages was further evi- ence of stream piracy between the two ystems.

Key to the species of *Percina* from the labama River:

. Snout usually conical and fleshy, projecting beyond lower jaw; mouth inferior. Interorbital area broad .... *Percina caprodes*
   Snout not as above; mouth terminal. Interorbital area narrow 2

. Anal fin of adult males when depressed extends far beyond posterior end of depressed soft dorsal fin 3
   Anal fin of adult males when depressed extends little beyond posterior end of depressed soft dorsal fin 4

. Dorsum with 6–12 dark blotches; lateral blotches tend to elongate as vertical bars. Spinous dorsal with a distinctive dark blotch near posterior margin and a smaller dark blotch at anterior base .... *Percina shumardi*
   Dorsum with 4 dark saddles; lateral blotches are oval-shaped. Spinous dorsal usually with interradial dark blotches along entire base .... *Percina uranidea*

4. Branchiostegal membranes moderately connected 5
   Branchiostegal membranes separate or narrowly connected 6

5. Lateral line scales 77–90; scales above lateral line 11–13; least caudal peduncle scales 30–34. Dorsal soft rays 12–14. Anterior base of soft dorsal with a triangular dark blotch; pectoral base with 1 or 2 dark spots .... *Percina lenticula*
   Lateral line scales 46–64; scales above lateral line 4–8; least caudal peduncle scales 16–25. Dorsal soft rays 10–13. No dark blotch on base of anterior rays of soft dorsal; no dark spots on the pectoral fin bases .... *Percina nigrofasciata nigrofasciata*

6. Subocular bar absent; 3 basicaudal spots; adult males with broad bars crossing back .... *Percina palmaris*
   Subocular bar present; a single median basicaudal spot; no broad bars crossing back 7

7. Premaxillary frenum absent or slightly developed, rarely well developed. Back with tessellated markings .... *Percina copelandi*
   Premaxillary frenum well developed. No tessellated markings on back .... *Percina maculata*

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Supplementary Material

The material examined in this study is listed below in alphabetical order (*P. lenticula* material is given above). Data include only the state, museum catalog number, and river system.

P. aurantiaca. Virginia: UMMZ 103446, Powell R.; USNM 40585, 162218, Holston R. North Carolina: USNM 37175, 92535, Tennessee R.; UMMZ 156985, USNM 40567, Watauga R.; UMMZ 156621, Little Tennessee R. Tennessee: USNM 48203, Tennessee R.; CU 41415, UMMZ 129572, Little Pigeon R.; CU 24630, Little R.; CU 22080, 30691, UMMZ 170938, 171250, Obed R.

P. caprodes. New York: CU 34967, 43078, 28789, Oswego R.; CU 5322, Chautauqua L. Pennsylvania: CU 8238, Shenango R. Michigan: CU 25397, Gun L. Indiana: CU 32134, Wabash R. West Virginia: CU 32489, Elk R. Kentucky: CU 41359, Cumberland R. Tennessee: CU 23293, Cherokee L.; CU 23409, French Broad R. Georgia: CU 24905, Coosawattee R.; CU 17594, Etowah R.; CU 42564, Coosa R. Alabama: CU 21919, Black Warrior R. Missouri: CU 34427, Meramec R.; CU 38418, James R. Arkansas: CU 35574, Illinois R. Kansas: CU 42231, Osage R. Oklahoma: CU 36532, Red R. Texas: CU 37225, Blanco R.; CU 37400, San Marcos R.

P. copelandi. New York: CU 44006, Lake Champlain; CU 44005, 44010, 44012, St. Regis R.; CU 2569, Lake Erie. Arkansas: CU 42257, Arkansas R. Oklahoma: CU 36536, Red R. Alabama: UMMZ 168633, 171761, Cahaba R.

P. crassa. Virginia: CU 11631, Roanoke R. North Carolina: CU 18634, 18636, Yadkin R.; CU 25899, Cape Fear R.; CU 10983, Catawba R.

P. cymatotaenia. Missouri: CU 32915, UMMZ 151955, Niangua R.; CU 37358, UMMZ 142322, 152290, 152485, Gasconade R.

P. evides. New York: CU 27042, Allegheny R. North Carolina: CU 10028, 41346, French Broad R. Minnesota: UM 19282, St. Croix R. Missouri: UMOMZ 4613, St. Francis R.; UMOMZ uncat., White R.; INHS uncat., Gasconade R.; CU 43442, Meramec R.

P. macrocephala. New York: CU 43179, Allegheny R. Pennsylvania: CU 9429, 9410, Allegheny R. West Virginia: CU 20862, 20853, Elk R. North Carolina: CU 10044, French Broad R. Tennessee: CU 24627, Little R.; UL 5586, Barren R.

P. maculata. New York: CU 8615, Allegheny R. Pennsylvania: CU 22979, Allegheny R. Indiana: CU 388, Kankakee R. Illinois: CU 7548, Kankakee R. Virginia: CU 8040, 24838, New R. Tennessee: CU 19147, Clinch R. Alabama: CU 15554, Tombigbee R.

P. nasuta. Arkansas: CU 41971, Little Red R.

P. n. nigrofasciata. South Carolina: CU 29847, Edisto R.; CU 20760, Salkehatchie R. Georgia: CU 17530, Apalachicola R.; CU 15963, 19805, Chattahoochee R.; CU 11799, Etowah R. Florida: CU 12124, 20749, Shoal R.; CU 16710, 43388, Blackwater R.; CU 12115, Choctawhatchee R.; CU 19253, Chipola R. Alabama: CU 19261, 16657, Alabama R.; CU 17163, Chattahoochee R.; CU 17664, Apalachicola R.; CU 16148, Escambia R. Mississippi: CU 11763, Pascagoula Dr.

P. n. raneyi. South Carolina: CU 19599, Savannah R.

P. notogramma. West Virginia: CU 25395, 4909, Williams R. Virginia: CU 8324, 9708, James R.; CU 10999, Rappahannock R.; CU 29902, York R.

P. oxyrhyncha. West Virginia: CU 20868, Ganley R.; CU 20839, 20855, 20863, 20868, 32280, 32497, 32498, Elk R. Virginia: CU 9502, 22544, 24954, 25359, New R.

P. palmaris. Georgia: GSC 43, 46, CU 28292, 42301, Chattahoochee R.

P. pantherina. Oklahoma: UMMZ 167122, Mountain Fork R.; UMMZ 167121, Little R.

P. peltata. New York: CU 42510, Susquehanna R.; CU 34117, 42756, Delaware R. Maryland: CU 31514, Potomac R.

P. phoxocephala. Illinois: CU 32115, Wabash R. Kentucky: UL 5632, Licking R. Missouri: CU 32821, Missouri R.

P. rex. Virginia: CU 20766, 8453, 16910, 11560, 24782, Roanoke R.

P. s. sciera. Illinois: CU 42024, Vermilion R. Indiana: CU 933, Bean Blossom Cr. West Virgina: CU 4743, 20910, Ohio R.; CU 32518, Pola R.; CU 43414, Elk R. Tennessee: CU 19144, Clinch R.; CU 24659, Elk R. Mississippi: CU 24932, 42165, Coldwater R.

P. s. apristis. Texas: CU 37399, 23426, 771, Guadalupe R.

P. sciera. Missouri: CU 42296, Little R.; CU 24285, Black R. Arkansas: CU 36365, Arkansas R. Texas: CU 21932, San Jacinto R.; CU 3907, Buffalo Bayou.

P. shumardi. Michigan: USNM 81563, Au Sable R. Indiana: CU 32134, 32236, Wabash R. Illinois: CU 3460, Big Muddy R. Iowa: UMMZ 173461, Mississippi R. Oklahoma: CU 24427, 25766, Neosho R. Mississippi: CU 14902, Pearl R.; UMMZ 157753, Tombigbee R.

P. squamata. North Carolina: UMMZ 156239, French Broad R.; UMMZ 156980, Toe R. Kentucky: UMMZ 168039, 177816, Rockcastle R. Tennessee: UMMZ 171253, Obed R.

P. uranidea. Missouri: CU 42301, Little R. Louisiana: CU 37384, TU 7965, Pearl R. Mississippi: CU 12647, Leaf R.; UMMZ 157757, Tombigbee R.; UMMZ 173826, Pearl R. Georgia: UMMZ 156697, Etowah R.

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SALMON SEROLOGY

by G. J. Ridgway and F. M. Utter

Included in the International North Pacific Fisheries Commission program of research on problems of the Protocol are serological studies. The objectives of these studies are to develop and apply serological and biochemical methods for distinguishing races of salmon on the high seas and to apply these methods to various other important salmon biology problems.

This research has included studies on differences in serum proteins, studies on differences in red cell antigens and studies on methods of detecting the onset of sexual maturation.

Studies on Red Cell Antigens

Evidence of individual variations in red cell antigens (blood types) in several species of Pacific salmon has been presented previously (Ridgway *et al.*, 1958; Ridgway and Klontz, 1960; Ridgway and Utter, 1963). Our most important finding has been that sera produced by immunizing one rainbow trout with the blood of another (isoimmune sera) would detect blood types in several species of Pacific salmon.

This year we have isoimmunized over 125 rainbow trout, most of which produced detectable antibodies. These trout were bled repeatedly so that relatively large supplies of antisera are available. All previously prepared sera of which we had an adequate supply, and sera resulting from the first 50 trout immunized this year, were tested with a panel of red cells from 30 rainbow trout. Those sera from a given individual showing the same specificity were pooled and either absorbed or diluted to give relatively large supplies of reagents with precise specificities. Thirty-four of these were selected and tested with the cells of sockeye salmon from one or more areas. The most promising 23 of these reagents were used to test as many 1963 Bristol Bay sockeye salmon samples as time and manpower permitted.

Results of these tests are shown in Table 18. Chi-square tests indicate that the characters detected by at least 14 of the 23 reagents vary significantly in their frequency of occurrence among tributary populations in the Naknek system, and the characters detected by 19 of the 23 vary significantly in their frequency of occurrence among the populations sampled in the major Bristol Bay rivers. In view of the practical application of these reagents, which we have already made, and their apparent potential utility, we intend to concentrate our blood typing efforts on their use. In order to apply these reagents to distinguishing Asian from North American salmon, tests will have to be run on salmon which we are reasonably certain are of Asian origin. We hope to conduct such tests in the future.

Research on Serum Antigens

Our previous findings involving two serum antigens of sockeye salmon which varied between samples taken in Asian and North American areas have been published (Ridgway *et al.*, 1962). Under certain conditions the presence of hemoglobin in hemolyzed whole frozen blood samples interferes with the tests for these antigens. For this reason only those samples in which the serum has been separated from the cells before freezing are currently used.

Many such serum samples were collected on the MV *Bertha Ann* in 1962 from areas where Asian and American sockeye salmon stocks are considered to intermingle, as well as from areas where either Asian or North American sockeye salmon stocks are considered to predominate. Selected samples were used to screen antisera collected from over 80 rabbits. Since none of these sera were found to duplicate the Antigen I and II specificities previously studied, two antisera with distinct specificities for antigens varying among individual sockeye salmon were selected for study. Both were available in sufficient quantities to insure an adequate supply for future testing. One was a rabbit anti-chum salmon serum. The factor it detects has been named the " C " factor. The other was a rabbit anti-sockeye salmon serum. The character it detects has been named the " H " factor. Additional antibodies detecting ubiquitous characters were removed from this antiserum by absorption with " H " negative sera. Both quantitative and qualitative tests were run for these factors using double and single diffusion precipitin methods. The principles of such tests have been described previously (Ridgway *et al.*, 1962) and will not be discussed here.

Results of testing the 1962 sockeye salmon serum samples for factor " C " are presented in Table 19; values obtained in chi-square tests of homogeneity among these samples are presented in Table 20. The frequency of occurrence of the " C " factor did not differ significantly for the samples within Western Alaska or within the three groups of high seas sets.

The usefulness of the " C " factor in studying the Protocol problems is questionable since the samples

International North Pacific Fisheries Commission, Annual Report 1963,
Vancouver, Canada, p. 149-154, 1964.

TABLE 18. Reactions of Bristol Bay sockeye salmon erythrocytes

Isoimmune serum:		96			101			259			$261P_1$		
Area	Date	Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cen positi
Naknek													
Main stream	7- 3	20	2	10	20	11	55	20	2	10	20	14	70
	7- 5	10	7	70	10	5	50	10	2	20	10	3	30
	7-15	29	16	55	29	3	10	29	14	48	29	18	62
American River	7-30	27	6	22	27	5	19	27	8	30	20	11	55
Hardscrabble Creek	8- 8	31	10	32	31	2	7	27	1	4	31	23	74
Brooks River	8-18	24	4	17	24	7	29	24	2	8	22	11	50
Hidden Creek	8-16	26	13	50	26	8	31	26	16	62	26	21	81
Egegik	7-10	41	14	34	39	9	23	19	7	37	39	22	56
	7-12							20	15	75			
Branch River	7- 6	20	5	25	20	6	30	20	8	40	20	11	55
Wood River	7- 6	22	7	32	22	4	18	22	15	68	22	11	50
Ugashik	7-19	21	1	5	21	2	10	21	9	43	20	11	55
Kvichak	7-10	29	11	38	29	17	59	29	6	21	29	21	72
Chi-square tests: (degrees of freedom in parentheses)													
Naknek			25.27 (6)**			23.38(6)**			36.8 (6)**			12.67 (6)*	
Egegik									10.47 (1)**				
Bristol Bay			33.7 (11)**			42.3(11)**			63.42(12)**			16.49(11)	

TABLE 18.

Isoimmune serum:		277			$282P_1$			$282P_2$			$284P_1$		
Area	Date	Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cen positive
Naknek													
Main stream	7- 3	20	8	40	20	3	15				20	2	10
	7- 5	10	5	50	10	0	0						
	7-15												
American River	7-30	27	6	22									
Hardscrabble Creek	8- 8	31	7	23	31	11	36	31	29	94	31	8	26
Brooks River	8-18				24	12	50	24	14	58			
Hidden Creek	8-16												
Egegik	7-10	39	24	62	41	2	5						
	7-12												
Branch River	7- 6	20	12	60	20	5	25						
Wood River	7- 6	22	18	82	22	2	9						
Ugashik	7-19												
Kvichak	7-10	29	8	28	29	2	7				26	0	
Chi-square tests: (degrees of freedom in parentheses)													
Naknek			4.5(3)			11.3(3)*			9.7(1)**				
Egegik													
Bristol Bay			30.2(4)**			43.9(7)**						8.6(2)*	

* Significant at the 95 per cent level.

** Significant at the 99 per cent level.

with 23 rainbow trout isoimmune sera, 1963.

261P$_2$			268			269			272			276		
Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cent positive
20	17	85	20	8	40	20	5	25	20	15	75	20	16	80
			10	6	66	10	7	70	10	8	80	10	5	50
			29	5	17				29	14	48			
27	22	82	27	2	7	27	16	59	27	11	41			
31	30	97	31	5	16	31	20	65	31	8	26	31	29	94
24	17	71	24	7	29				24	6	25	24	16	67
26	24	92	26	7	27				26	16	62			
						19	0	0						
22	19	86	}39	5	13				}39	15	39	19	9	47
						22	8	36						
			20	8	40	20	8	40	20	8	40	20	14	70
			22	6	27	22	4	18	22	7	32	22	9	41
26	22	85	29	16	55	29	6	21	29	25	86	29	26	90
9.26 (4)			16.12(6)*			9.6(3)* 8.6(1)**			23.6 (7)**			10.7(3)*		
0.016(2)			33.02(10)**			39.6(8)			44.9(10)**			30.5(7)**		

Continued.

284P$_2$			287P$_1$			287P$_2$			289P$_2$			291		
Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cent positive
20	2	10	20	16	80	20	12	60	20	15	75	}30	8	27
			10	4	40	10	8	80	10	7	70			
			29	10	35	27	17	59						
			27	6	22									
31	4	13	31	9	29	31	11	36	29	25	86			
			24	2	8	24	2	8						
			26	12	46	26	10	39						
									19	4	21	19	0	0
			}19	10	53	41	22	54	22	18	82	22	11	50
			20	12	60	20	12	60	20	18	90	20	13	65
			22	12	55	22	11	50				22	9	41
			21	10	48	21	14	67						
26	0	0	29	11	38	29	15	52	29	23	79	29	12	41
			33.1 (6)**			23.5 (5)**			1.5(2)					
									15 (1)**			13 (1)**		
3.4(2)			39.6(11)**			29.2(10)**			33.7(4)**			21.2(5)**		

TABLE 18. Continued.

Isoimmune serum:		295			3127			3128			3167			258	
Area	Date	Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cent positive	Total sample	No. positive	Per cent positive	Total sample	No. positive
Naknek															
Main stream	7- 3				20	9	45	20	8	40	49	3	6	20	15
	7- 5				10	8	80	10	8	80				10	5
	7-15	29	21	72										29	10
American River	7-30				27	8	30	27	18	67					
Hardscrabble Creek	8- 8														
Brooks River	8-18														
Hidden Creek	8-16				26	18	69	26	9	35					
Egegik	7-10	19	11	58	19	9	47	39	26	67	41	2	5	18	1
	7-12	20	19	95	20	18	90								
Branch River	7- 6				20	15	75	20	18	90	20	9	45	20	15
Wood River	7- 6	20	11	55	22	12	55				22	0	0	22	3
Ugashik	7-19	21	17	81							21	5	24	21	9
Kvichak	7-10	29	27	95	29	16	55	29	15	52	29	1	3	29	5
Chi-square tests: (degrees of freedom in parentheses)															
Naknek						12(3)**			9.8(3)*						7.8(2)*
Egegik			7.6(1)**			8.4(1)**									
Bristol Bay			17.8(5)			25.9(8)**			32.1(6)**			34.3(5)**			43.3(4)**

TABLE 19. Incidence of " C " factor in 1962 sockeye salmon sera.

Area	Date	Number positive	Number negative	Per cent positive
Western Alaska				
Karluk	6-22	22	12	64.7
Kuskokwim	6-27	11	7	61.1
Wood River	7-4	7	7	50.0
Naknek	7-5	33	18	64.7
Egegik	7-11	12	13	48.0
Ugashik	7-18	14	9	60.9
Kvichak	7-3	15	9	62.5
”	7-7	12	11	52.2
”	7-12	11	8	57.9
High Seas (MV *Bertha Ann*)				
Set 1	5-30	5	7	41.6
Set 2	6-1	10	10	50.0
Set 3	6-2	12	10	54.5
Set 4	6-3	11	20	35.5
Set 5	6-4	3	8	27.3
Set 6	6-5	4	14	22.2
Set 8	6-10	12	14	42.6
Set 9	6-11	20	15	57.1
Set 10	6-16	12	19	38.7
Set 11	6-17	6	5	54.5
Set 12	6-19	2	10	16.7
Set 13	6-20	4	5	44.4
Set 14	6-25	22	14	61.1
Set 15	6-26	12	11	52.2
Set 16	6-27	12	10	54.5
Set 17	6-28	8	14	36.4

Locations of sets are shown in INPFC Annual Report for 1962.

TABLE 20. Results of chi-square tests of homogeneity fo incidence of " C " factor among 1962 sockeye salmon serum samples.

Areas compared	Chi-square value	Degree freedo
Kvichak—within	0.529	2
Western Alaska—within	3.14	6
High Seas:		
Group 1 (Sets 1 through 6)—within	6.2	5
Group 2 (Sets 8 through 13)—within	7.1	5
Group 3 (Sets 14 through 17)—within	3.37	3
Groups 1, 2, 3—within	3.75	2
Western Alaska *vs.* Group 3	1.2	1

in group 3, taken in the northwestern Pacific after t migration of Bristol Bay sockeye, are not significan different from our Western Alaskan samples.

The results of tests of 1962 sockeye salmon blo samples for the " H " factor are shown in Table Results of chi-square tests of homogeneity on th data are presented in Table 22. Heterogeneity demonstrated not only within Western Alaska a Bristol Bay, but also within the Kvichak samp taken at intervals of four and five days. Group (sets 1 through 6) and group 3 (sets 14 through 1 of the high seas samples also are markedly heterogen ous. Since the Western Alaska samples are heter

TABLE 21. Incidence of “ H ” factor in 1962 sockeye salmon sera.

Area	Date	Number positive	Number negative	Per cent positive
Western Alaska				
Karluk	6–22	32	3	91.4
Kuskokwim	6–27	11	7	61.1
Wood River	7–4	8	3	72.7
Naknek	7–5	36	22	62.1
Egegik	7–11	22	3	88.0
Ugashik	7–18	21	2	91.3
Kvichak	7–3	19	6	76.0
”	7–7	10	13	43.5
”	7–12	20	2	90.9
High Seas (MV *Bertha Ann*)				
Set 1	5–30	5	8	38.5
Set 2	6–1	9	2	81.9
Set 3	6–2	20	4	83.3
Set 4	6–3	19	14	57.6
Set 5	6–4	18	1	94.7
Set 6	6–5	17	5	77.3
Set 8	6–10	5	21	19.2
Set 9	6–11	12	28	30.0
Set 10	6–16	13	22	37.1
Set 11	6–17	3	12	20.0
Set 12	6–19	9	11	45.0
Set 13	6–20	4	8	33.3
Set 14	6–25	35	5	87.5
Set 15	6–26	18	4	81.8
Set 16	6–27	16	4	53.3
Set 17	6–28	23	0	100.0

Locations of sets are shown in INPFC Annual Report for 1962.

eneous with respect to the frequency of the “ H ” actor, its use in separation of Asian and North Ameri-an stocks would be complicated. It might prove f value when used in combination with other charac-ers.

Further studies have been made on serum antigens sing the techniques of immunoelectrophoresis (Krauel nd Ridgway, 1963) and starch gel electrophoresis Smithies, 1959). Individual variations in sockeye almon sera have been demonstrated, but further basic esearch on the application of these methods to salmon era will be required before they can be applied to opulation problems.

ESEARCH ON METHODS OF DETECTING THE ONSET OF MATURATION

Our studies on maturity have been conducted y two methods—serology and histology. In our erological studies on the previously described antigen Ridgway *et al.*, 1962) which occurs in the sera of mature or maturing female salmon, it has been found that female sockeye salmon possess this antigen as early as February.

TABLE 22. Results of chi-square tests of homogeneity for incidence of “ H ” factor among 1962 sockeye salmon serum samples.

Areas compared	Chi-square value	Degrees of freedom
Kvichak—within	12.7**	2
Bristol Bay—within	23.9**	6
Western Alaska	18.4**	6
High Seas:		
Group 1 (Sets 1–6)	17.86**	5
Group 2 (Sets 8–13)	5.23	5
Group 3 (Sets 14–17)	20.57**	3

* Significant at the 95% level.
** Significant at the 99% level.

Histological studies conducted in our laboratory by Miss Kathleen Ladue have largely confirmed those of Ishida *et al.* (1961). However, in some male sockeye taken on the high seas as early as January and February, the onset of maturity is evident histologically by the presence of primary and secondary spermatocytes and the development of the tunica propria even though the testes weigh less than one gram.

SUMMARY

Rainbow trout isoimmune sera of numerous specificities have been found to detect blood groups in Pacific salmon. Twenty-three of these reagents were used to test 1963 Bristol Bay sockeye samples. Marked heterogeneity was found in many instances between main river systems as well as between tributary samples from within the Naknek River. Further blood grouping work will be concentrated on the use of these reagents.

Rabbit antisera of two distinct specificities detecting characters called “ H ” and “ C ” were used to test sera of high seas and Bristol Bay sockeye salmon taken in 1962. Lack of significance between Western Alaska samples and the high seas group most likely to represent Asian samples makes the “ C ” factor of doubtful utility for Protocol problems. Heterogeneity of the distribution of the “ H ” factor presents a complex picture which does not necessarily rule out its usefulness for separation of Asiatic and North American stocks.

Individual variations in sockeye salmon sera have been demonstrated using the techniques of immunoelectrophoresis and starch gel electrophoresis.

An antigen indicative of maturation in female salmon has been detected in sockeye as early as February. The onset of maturity in male sockeye salmon taken at the same time has been detected histologically.

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EFFECT OF REDUCED WATER TEMPERATURE ON FISHES OF TAMPA BAY, FLORIDA

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EFFECT OF REDUCED WATER TEMPERATURE ON FISHES OF TAMPA BAY, FLORIDA

Gordon R. Rinckey and Carl H. Saloman

Estuaries connected with the Gulf of Mexico are characterized by extensive shallow water areas which at times are subjected to rapid temperature fluctuations. The reaction of marine organisms to environmental changes is of importance to biologists engaged in estuarine ecological research. Instances of massive fish mortality, especially among sublittoral species, have resulted from a marked lowering of water temperature. Gunter (1941) and Gunter and Hildebrand (1951) reported such occurrences on the Texas coast. Fish kills attributed to rapid temperature reduction have also been recorded from the Florida Gulf coast by Storey and Gudger (1936) and Springer and Woodburn (1960).

During the evening of December 12, 1962, northwest winds of 20-30 mph. and a low air temperature of 18.3°F were recorded in the Tampa Bay area. This was the coldest temperature reported since the initiation of records in 1890. These severe conditions made it possible to observe the effects of rapid temperature depression on fish in Tampa Bay.

Two major fish kills were observed. The first occurred on the morning of December 13 in Old Tampa Bay below the dam of Bass Lake, a freshwater impoundment (fig. 1). This site is a brackish-water, mud-bottom habitat having an annual salinity range of 4 to 28 o/oo. Water depth varies from two to four feet. On the following morning, December 14, another kill was noted in Boca Ciega Bay, north of Pass-a-Grille channel (fig. 1). These waters range in salinity from 28 to 36 o/oo and in depth from 4 to 12 feet. There are numerous channels and fills in the area. Water temperatures at the two locations are similar.

Observations

Water temperature in Old Tampa Bay ranged from 14.3 to 15.0°C on December 10. During the fish kill of December 13, a surface water temperature of 9.6°C and a salinity of 14.42 o/oo were recorded at 9 a.m. The bottom was completely covered with fish in an area 50 feet square at a depth of two feet. Most of these

TABLE 1

Species of fish affected by lowered temperature on December 13-14, 1962, in Tampa Bay, Florida

Area and Date	Water Temp. (°C)	Sal. (o/oo)	Species	Size Range (mm.)	Total Number Collected	Condition
Bass Lake, Old Tampa Bay (Dec. 13)	9.6	14.42	*Diapterus plumieri* *	55–108	152	Dead, few stunned
			Ictalurus nebulosus	92–104	6	Dead
			Eucinostomus argenteus	40–64	5	Dead
			Mugil trichodon	62–110	2	Dead
			Centropomus undecimalis	123	1	Dead
Pt. Pinellas, Central Tampa Bay (Dec. 13)	11.2	28.24	*Eucinostomus gula*	46–50	2	Stunned
			Lutjanus synagris	115	1	Stunned
			Chilomycterus schoepfi	105	1	Dead
			Synodus foetens	53	1	Dead
Big Bayou, Central Tampa Bay (Dec. 13)	10.8	——	*Microgobius gulosus*	23–37	6	Stunned
			Harengula pensacolae	138	1	Dead

Boca Ciega Bay (Dec. 14)	10.4	32.97	*Caranx hippos*	120–347	80	Dead and stunned
			Selene vomer	163–287	17	Dead and stunned
			Lutjanus synagris	48–133	4	Dead
			Chilomycterus schoepfi	58	1	Dead
			Monocanthus hispidus	176	1	Dead
			Lactophrys quadricornis	182	1	Dead
			Harengula pensacolae	132	1	Dead
			Mystriophis intertinctus	705	1	Dead
			Diodon sp.	62	1	Dead
Coffee Pot Bayou, Tampa Bay (Dec. 14)†	11.8	—	*Carnax hippos*		100–200	Dead
			Trachinotus falcatus		15	Dead
			Chaetodipterus faber		5	Dead
			Harengula sp.		5	Dead
			Centropomus undecimalis		5	Dead

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[*] The Florida State Board of Conservation also reported this species killed in large numbers on December 13 and 14 in Hillsborough Bay from the Alafia River south to the Ruskin area.

[†] Data from Mr. Martin Moe, Florida State Board of Conservation. Numbers of fish were estimated.

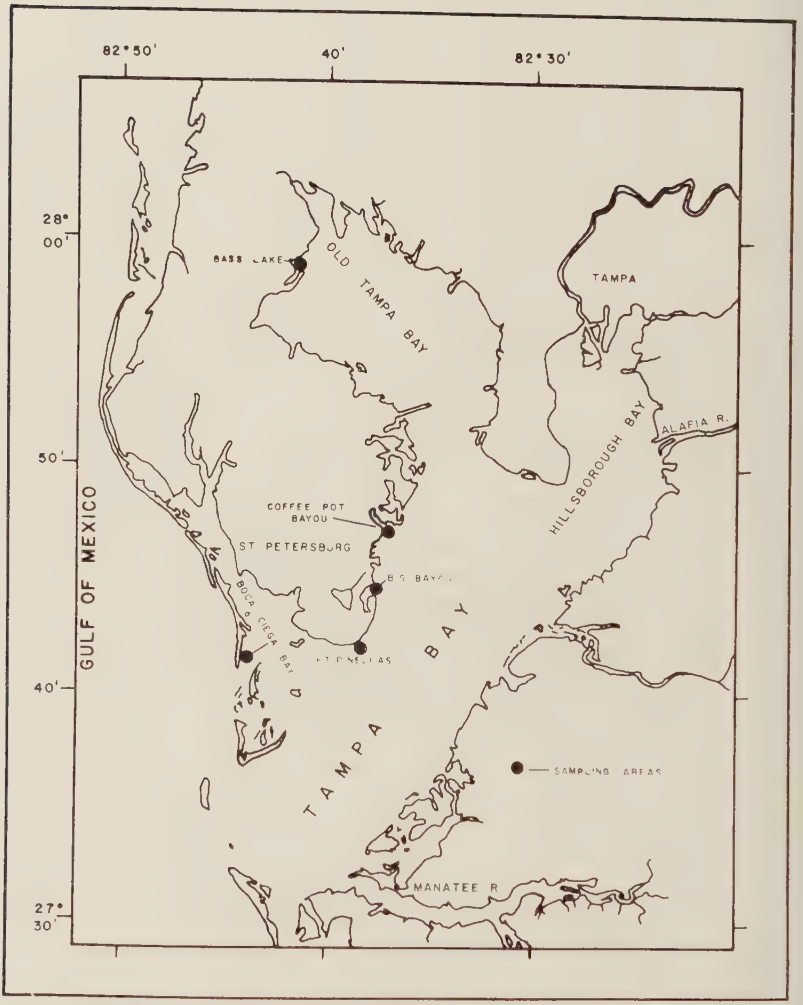

Fig. 1. Stations sampled during fish kills on December 13-14, 1962, in Tampa Bay, Florida.

fish were dead, and those still alive exhibited a loss of equilibrium. The majority of the fish affected were striped mojarra (*Diapterus plumieri*). The tide at this time was low (ebb), and the water was clear. Along the high tide mark, *D. plumeiri* were frozen solid, an indication that the kill had begun as the tide receded. The remaining fish collected dead at Bass Lake (table 1) included: brown bullhead (*Ictalurus nebulosus*), spotfin mojarra (*Eucinostomus argenteus*), fantail mullet (*Mugil trichodon*), and snook (*Centropomus undecimalis*). A seine-haul produced the following species which were unharmed: longnose killifish (*Fundulus similis*), gulf killifish (*F. grandis*), sheepshead minnow (*Cyprinodon variegatus*), rainwater killifish (*Lucania parva*), and blackcheek tonguefish (*Symphurus plagiusa*). Juvenile red drum (*Sciaenops ocellata*), common in the area during November, were not collected or seen during the freeze.

In Boca Ciega Bay the first fish kill was noted at 9 a.m., December 14 (table 1). The surface water temperature was 10.4°C and the salinity 32.97 o/oo. Crevalle jack (*Caranx hippos*) appeared to be affected in greater numbers than any other species in that area. We estimated that 300-500 jacks were killed in the areas sampled. These were found dead on the beaches and were netted, in a stunned condition, from the surface of the water. Those on the beaches appeared to have died as the tide receded. The fish collected ranged in size from 120 to 347 mm. but the majority were in two distinct size groups (120-150 mm. and 260-347 mm.). All specimens examined were immature. The second most numerous species affected in the same area was the lookdown (*Selene vomer*). Fourteen of the 17 specimens collected were dead on the beaches, while the others were taken from the surface of the water in a stunned condition. Additional species, collected dead from the beaches in Boca Ciega Bay, included lane snapper (*Lutjanus synagris*), striped burrfish (*Chilomycterus schoepfi*), planehead filefish (*Monocanthus hispidus*), cowfish (*Lactophrys quadricornis*), scaled sardine (*Harengula pensacolae*), spotted spoon-nose eel (*Mystriophis intertinctus*), and porcupinefish (*Diodon* sp.).

Limited kills were observed at Point Pinellas and Big Bayou in central Tampa Bay on December 13 (table 1). Water temperature was 11.2°C, and 10.8°C, respectively, in the two areas. A seine-haul at Point Pinellas produced *F. similis*, *F. grandis*, *C.*

variegatus, tidewater silverside (*Menidia beryllina*), gulf pipefish (*Syngnathus scovelli*), and redfin needlefish (*Strongylura notata*), all in good condition. Young fantail mullet (*M. trichodon*), abundant at Pt. Pinellas during November, were not caught or observed during the freeze.

On December 14, at Coffee Pot Bayou in central Tampa Bay (fig. 1), the water temperature was 11.8°C at 5 p.m. The major species affected was *C. hippos.* Other species killed were permit (*Trachinotus falcatus*), Atlantic spadefish (*Chaetodipterus faber*), *Harengula* sp., and *C. undecimalis* (table 1). All dead fish were observed on the surface or near the shore.

Discussion

Fish kills associated with abnormal temperature reduction are common along the Florida Gulf coast (Storey and Gudger, 1936). The freeze of December 12-14 in the Tampa Bay area was the first and most severe cold spell of the winter. Air and water temperatures dropped rapidly. Nineteen fish species were adversely affected. The dominant fish killed were crevalle jack and striped mojarra. Cyprinodontids were tolerant of the low water temperatures. By December 17 water temperatures had increased in the sampling areas and no additional fish kills were observed.

Springer and Woodburn (1960) reported minor fish kills in the Tampa Bay area on December 13, 1957, when water temperature was as low as 13°C. Snook, barracuda, silver mullet, and striped mojarra were the predominant species affected. These fish kills occurred during another record cold winter when a low water temperature of 8.5°C was reported (Dragovich, Finucane, and May, 1961).

Storey (1937) observed that fish damaged most by a freeze at Sanibel Island, Florida, were tropical and subtropical species. Many of these species were also noted by the authors. They included: *C. hippos, L. synagris, L. quadricornis, C. schoepfi, C. undecimalis, M. intertinctus,* and inshore lizardfish (*Synodus foetens*). Two species found by the authors but not included in Storey's discussion were *D. plumieri* and *S. vomer.* Briggs (1960) gives the range of *D. plumieri* (*Eugerres plumieri*) as southwestern Florida to Bahia, Brazil, and west to Mexico. Springer and Woodburn (1960) stated that their collection of *D. plumieri* occurred in an area about 75 miles north of its reported range. This suggests that *D. plumieri* has a tropical and subtropical distribution. Joseph and Yerger (1956) listed *S. vomer* as being characteristic of tropical waters. The lookdown was not known to be common in Tampa Bay. Prior to the kill only three juveniles (28-43 mm.) were collected there in 18 months of sampling. All 17 specimens taken during the freeze were adults.

Our observations suggest that the rapid, short term reduction in water temperatures of Tampa Bay had detrimental effects primarily on tropical and subtropical fish species. Other fish, including the majority of important sport and commercial species, were apparently unharmed. The total effect on local fish populations appeared to be minor.

ACKNOWLEDGMENT

We wish to thank Mr. Martin Moe of the Florida State Board of Conservation, St. Petersburg, for data on the fish kill at Coffee Pot Bayou in central Tampa Bay.

SUMMARY

Freeze conditions in central Florida during the period December 12 through 14, 1962, lowered water temperatures rapidly in Tampa Bay. The effects of these conditions on Tampa Bay fish were noted. Nineteen fish species, the majority having tropical or subtropical distribution, were observed dead or stunned. *Diapterus plumieri* and *Caranx hippos* suffered the greatest mortality.

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TESTS OF INTERNAL TAGS FOR GREEN CRABS (CARCINUS MAENAS)

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ABSTRACT

A technique is described for inserting U-shaped monel metal tags into the body cavity of green crabs, *Carcinus maenas* (L.), at a site between the first and second abdominal segments. In the laboratory, tagging mortality of approximately 20% was observed. Tags were retained through ecdysis with comparable mortality during tests of disk tags or U-tags inserted at coxal or lateral spine sites. The internal tagging technique was developed for use in studies of migration and growth of the green crab, a predator of soft-shell clams, *Mya arenaria* L.

INTRODUCTION

Internal tags which were retained during ecdysis by green crabs, *Carcinus maenas* (L.), were tested in the laboratory. The internal tag was developed to provide a means of observing the migration and growth of individual crabs. Such information is needed to design effective methods of controlling green crab abundance. *Carcinus* is a predator of the soft-shell clam, *Mya arenaria* L., and is considered responsible for a decline of this species north of Cape Cod (Glude, 1955).

Various tags and marks have been used on arthropods, but none were considered suitable for green crabs. Tags and marks applied to the hard exoskeleton are lost during ecdysis. Some tags and marks that are retained through ecdysis were reviewed by Simpson (1961). Barbed and sutured tags have been retained, but could impede an animal's normal activities or be dislodged from the insertion site when the crab burrows. Holes punched in the uropods and telsons, a method used on lobsters, were undesirable because the marks are eventually obscured by new shell and tissue growth. Dawson (1957), Cargo (1958), and Costello (1959) reported successful marking with biological dyes. However, dyes eventually faded or were difficult to see through the pigmented exoskeleton of the green crab. Hayes (1961) described a "spaghetti" loop tag used on king crabs (*Paralithodes*), sewn around the arthral muscle that lies anterior to the joint between the carapace and abdomen. Such a conveniently located muscle could not be found in *Carcinus*.

To circumvent some of these disadvantages an internal tag and tagging technique were developed during 1956-1958 at the Bureau of Commercial Fisheries Substation in the Narragansett Marine Laboratory, University of Rhode Island, Kingston, Rhode Island. Extensive tests of the tag and tagging technique were conducted at the Bureau's Biological Laboratory, Boothbay Harbor, Maine, during 1959 and 1960.

PRELIMINARY TESTS OF TAGS AND TAGGING TECHNIQUES

The flexible, membranous joints between segments were chosen for tag insertion sites to reduce exoskeleton damage. Not all joints were suitable. Many were too small. Leg joints were unsuitable because Carcinus can autotomize its legs (Waterman, 1960). Tags were easily slipped into the body cavity through an abdominal joint and through the joint between the carapace edge and first abdominal segment.

Tag dimensions were delimited by examining internal anatomy. Two vital structures susceptible to damage, the heart and internal thoracic skeleton, lay in the path of tag insertion. The heart lies about in the center of the body mass and anterior to the tag insertion site. Measurements from the posterior edge of the heart to the tag insertion site determined the maximum length of a tag. Similarly, the maximum width of a tag was determined by measuring the distance between two internal processes of the thoracic skeleton that covers the bases of leg muscles. Both structures could be avoided in crabs 20 mm or larger by using tags not over 1/4 inch (6.35 mm) in diameter. All size measurements of crabs in this paper refer to carapace widths.

Three types of experimental tags were fabricated. (1) Disk tags 3.165, 4.76, and 6.35 mm in diameter were cut from 0.015-inch (0.381 mm) thick sheet metal using common paper punches. Fish strap tags (Rounsefell and Kask, 1943), 1.59 mm wide were modified (2) by cutting off and rounding the ends to form a flat tag 6.35 mm long, and (3) by cutting off and rounding the ends, then folding the tag to form a U with a finished length of 4.76 mm. These U-tags were inserted with a special tool; other tags were inserted with forceps.

Two insertion sites for disk tags were tested. Disk tags inserted at the joint between the carapace and abdomen were not retained through ecdysis. Dissections of dead, unmolted crabs revealed that the tags rested on a projection of the first abdominal segment that is overlapped dorsally by the carapace. One molted shell was found with the tag resting on this projection. Burrs on the edges of the disks anchored the tag to the molted shell. Disk tags were retained when inserted at the joint between the first and second abdominal segments. Dissections of tagged crabs revealed that the tags lay in soft body tissues without touching the hard exoskeleton. The latter site was chosen for subsequent tag insertions.

Several tests of tagging mortality indicated the most suitable tag size. In a test of the three disk sizes, crabs 20 to 49 mm were separated into three 10-mm size interval groups and held for 21 days (Table 1). Tagging caused high mortality in the crabs 20 to 29 mm, especially those tagged with the two largest disks. This might be expected, but not the anomalous situation in crabs 30 to 49 mm where mortality decreased with an increase in tag size. These data indicated that 4.76 mm and 6.35 mm disks were unsuitable for crabs less than 30 mm. Tag retention was not accurately observed because cannibalism occurred during molting.

Table 1. The percentage mortality of crabs tagged with disks

Crab size (mm)	Per cent mortality			
	Crabs tagged with			Untagged crabs
	3.165 mm disks	4.76 mm disks	6.35 mm disks	
20 to 29*	50	74	86	20
30 to 39*	24	18	16	14
40 to 49*	42	28	22	12

*50 crabs for each disk size were used.

To prevent cannibalism, in an experiment with the flat modification of strap tags, 120 crabs ranging in size from 20 to 39 mm were held in perforated plastic berry baskets 4.5 inches (11.33 cm) square and 3 inches (7.62 cm) deep. After 120 days, only 4% of these crabs were dead. As many as 86% molted, but only 9% of the molted crabs retained the tag. Apparently burrs on these tags prevented complete insertion into the body cavity, for molted shells were found with the tag stuck in the insertion site. This tag was not suitable, then, even though few mortalities occurred.

The U-shaped modification of strap tags and the following technique insured more complete tag insertion. A tool was used first to pierce the abdominal site and then to hold the tag for insertion (Fig. 1). The shaft diameter of the tool was slightly larger than the tag end and served as a shoulder preventing insertion beyond 4.76 mm, a depth twice the length of a U-tag. U-tags were found completely surrounded by soft body tissues when tagged crabs were dissected. Mortality from U-tags was not appreciably different from that with other tags. When 222 crabs of various sizes were tagged and held for 35 days, most of the crabs that molted retained the U-tags (Table 2). U-tags seemed most suitable, then, because they were easily inserted, caused relatively few mortalities, and were retained by many crabs through ecdysis.

Table 2. The percentage mortality and U-tag retention through a molt

Crab size (mm)	Number of crabs	Percentage		
		Died	Molted	Molted and retained the tags
20 to 29	17	12	29	100
30 to 39	146	16	24	89
40 to 49	28	4	11	100
50 to 69	31	23	0	0

TESTS WITH U-TAGS

The following materials and methods were used during subsequent experiments. Coded U-tags were 1.98 mm wide and of a finished 4.76 mm length, and made of monel metal, 0.010-inch (0.254 mm) thick, by the National Band and Tag Company, Newport, Kentucky. The crabs, held separately to prevent cannibalism, were placed in a tank 16 feet long and 18 inches wide with a water depth of 11 inches. Sources of decomposition such as excreta and dead crabs were removed periodically. Live soft-shell clams were fed to the crabs each week to promote

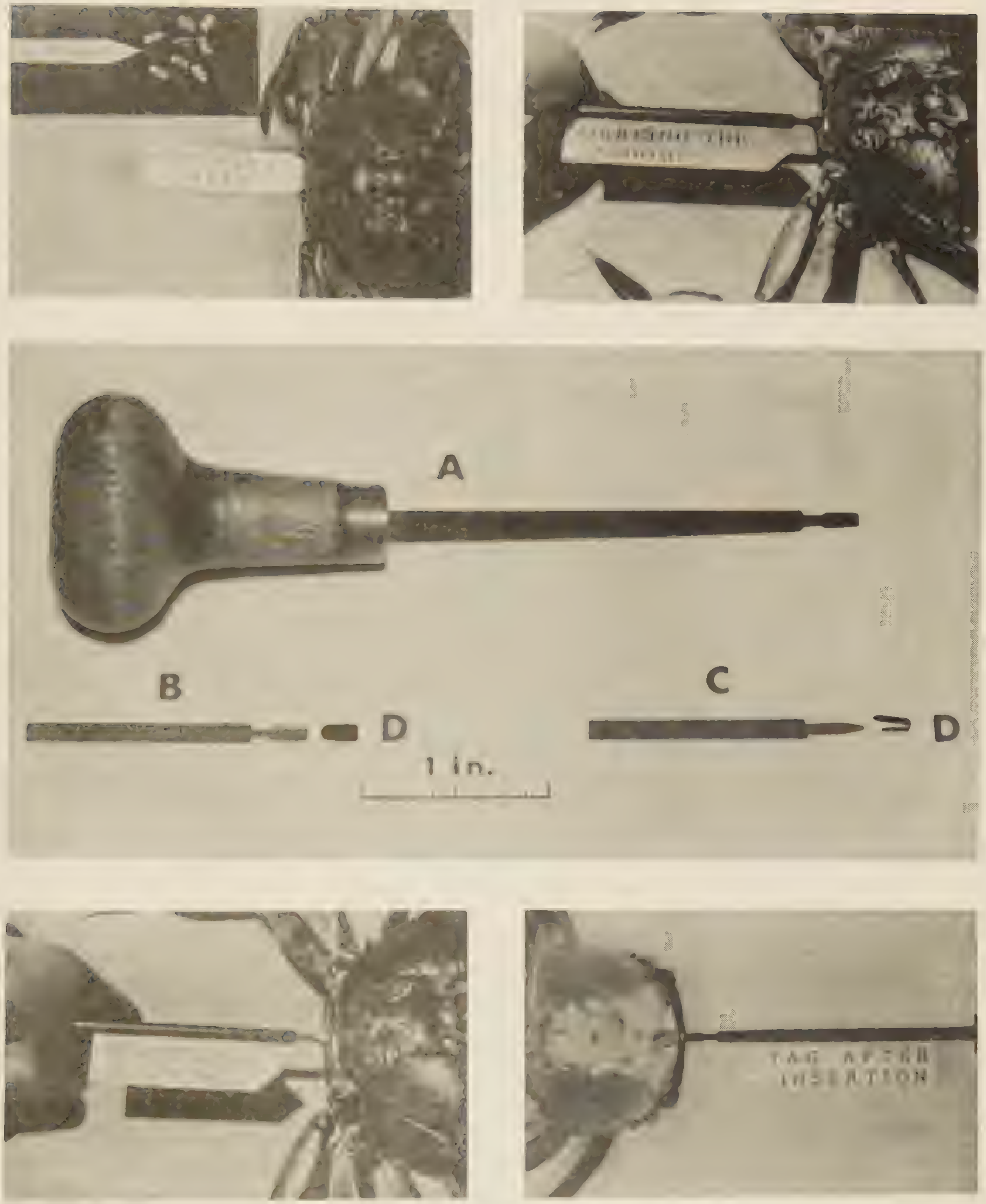

Fig. 1. The tagging technique. An insertion tool (A), as well as its top (B) and side (C) appearance in relation to U-tags (D).

growth and molting. Each crab was randomly placed within the tank with regard to size, sex, and method of tagging.

Tagging mortality and tag retention

During 1959 two tests were conducted to observe the mortality and tag retention of crabs bearing U-tags. Crabs, caught just prior to each test, were separated into 20 size classes with 1 mm intervals. A male and a female were drawn from each of the 20 size classes, to total 40 untagged controls for each test. A similar selection of 152 crabs was tagged. The first test included crabs 20 to 39 mm, whereas the second included crabs 25 to 44 mm because smaller crabs were not available. The intervals 20 to 29 mm, 30 to 39 mm, and 40 to 44 mm were used to group the data by crab size, and data from both tests were combined for analysis.

Crabs tagged for the first test 1 May 1959 were held for 214 days and those tagged for the second test 10 July 1959 were held 131 days. A 13% escapement occurred from the plastic berry baskets used in the first test and a 7% escapement from compartmented trays used in the second test. Only 27% of the tagged crabs 20 to 29 mm were alive on the fourteenth day (Fig. 2), indicating that the tags caused a high mortality. Larger crabs were less affected by the tags during the same 2-week period: 78% of the 30 to 39 mm and 89% of the 40 to 44 mm crabs were alive on the fourteenth day. No mortalities of control crabs 40 to 44 mm occurred until the ninth week at which time 65% of the tagged crabs were alive. Thus, the larger crabs were less affected by tagging.

Most tagged crabs died before molting in both tests (Table 3). Apparently many deaths of crabs less than 40 mm were due to factors other than tagging, for there was a high mortality in controls. Most molted crabs retained the U-tag. Though survival was low in the first test, 11 crabs molted and 9 retained the tag. More crabs molted (66) during the second test and most (62) retained the tag. A high percentage (92%) of molted crabs retained the tags, but only a few were alive at the end of the tests.

Insertion sites and tags

Tagging mortalities during 1959 suggested that other insertion sites should be investigated. To this end a total of 432 crabs, 30 to 39 mm, were divided into six groups of 72 crabs each. Each group contained four crabs of each sex and from 1-mm size categories,

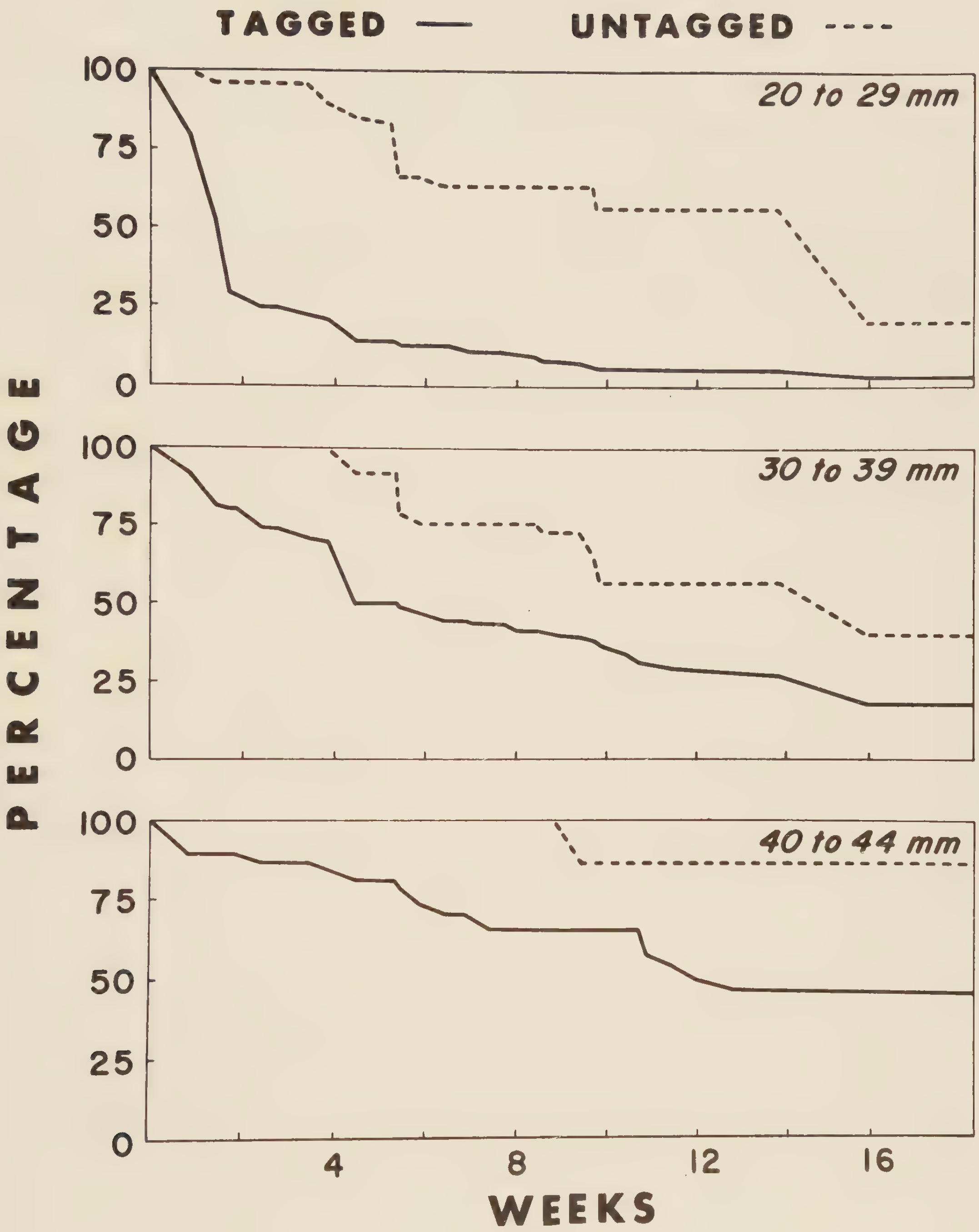

Fig. 2. The combined percentage survival of green crabs tagged with U-tags during two experiments in 1959.

Table 3. The mortality of tagged and untagged crabs, and the retention of tags after molting.

Test, tagged and untagged crabs[a]		Number of crabs					
		Pre-molted that		Post-molted that		Post-molted that retained the tag and	
		Died	Lived	Died	Lived	Died	Lived
No. 1	Tagged 136	125	0	10	1	8	1
	Untagged 31	20	2	7	2		
No. 2	Tagged 143	65	12	44	22	42	20[b]
	Untagged 36	7	5	10	14		

[a] Less escapement from the holding cages.

[b] One crab molted twice and retained the tag both times.

excepting the sizes 32, 33, 36, and 37 mm that had only three of each sex. One untagged group served as controls. Three groups carried U-tags inserted either at a lateral spine, a coxal joint, or the abdominal site. Two groups carried metal disks 4.76 mm in diameter at either the lateral spine or abdominal site. The lateral spine sites were made by cutting off a portion of the carapace and spine large enough to admit a tag. Tag insertions were made to a depth of 4.76 mm or less and in a mesiad direction. The coxal sites were made by forcing crabs to autotomize a cheliped. Each U-tag was compressed to make it as small as possible before insertion into the coxal site. Disks were considered too large to insert in the coxal site without causing extensive damage to the hard exoskeleton.

The test began 16 June 1960 and ended 127 days later. New holding trays, each with compartments that were 4.5 inches (11.33 cm) long, 3 inches (7.62 cm) wide and deep, were used and only 2% of the crabs escaped during the test. The survival of tagged crabs ranged from 67% to 81% in the five groups on the fourteenth day of the test (Fig. 3). Crab deaths were attributed to tagging since no controls died

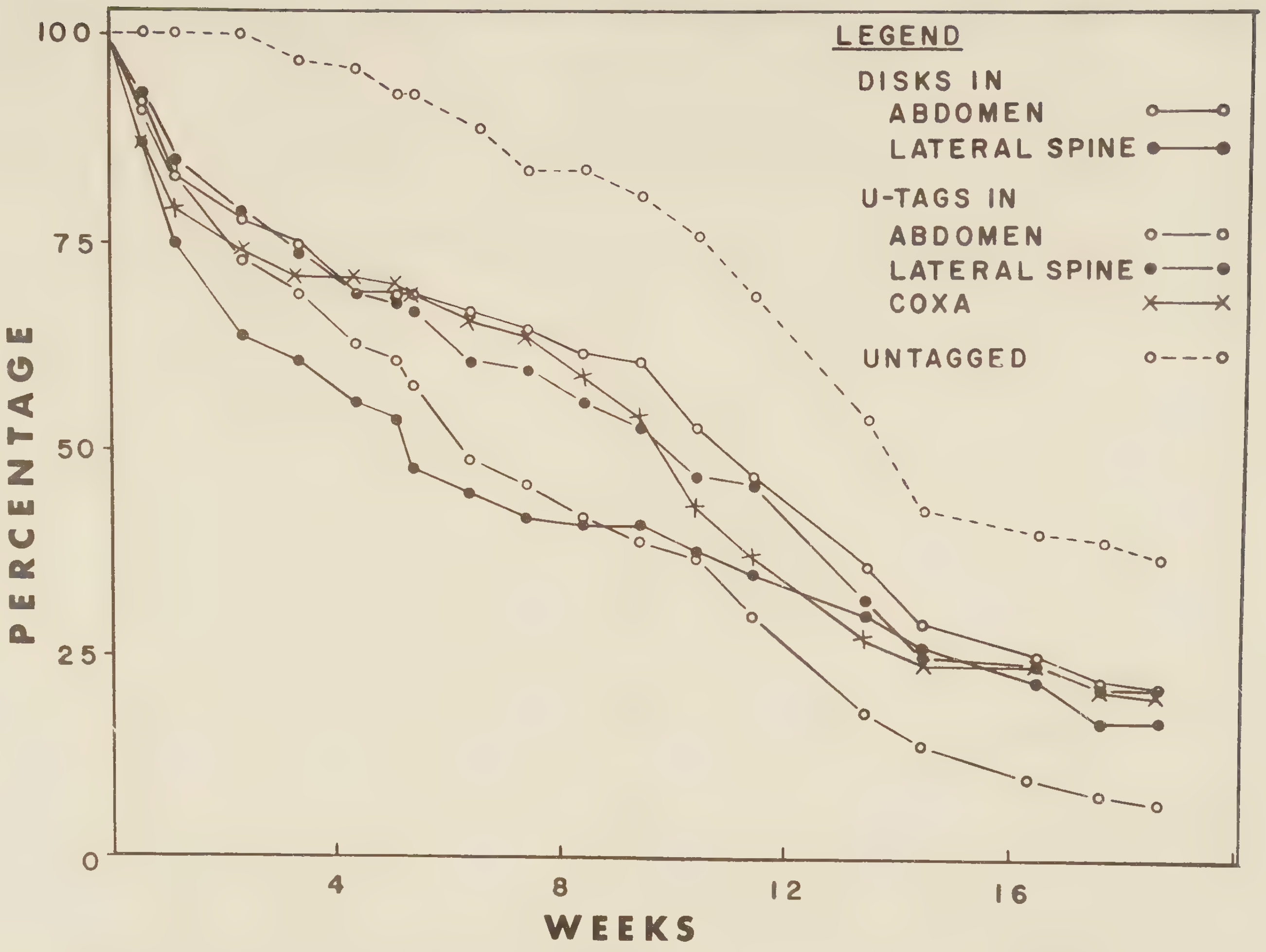

Fig. 3. The percentage survival of green crabs during a test of two types of tags at three insertion sites.

during this period. After this initial period, a mortality of both tagged and control crabs was observed. At termination, survival in the five tagged groups ranged from 7 to 21% and 37% of the controls were alive. In a chi-square test comparing the mortality data (Table 4) for each tagging technique, no one technique was found to be significantly different.

Disks inserted at the abdominal and lateral spine, as well as U-tags at the lateral spine or coxal site, were retained by 17 to 29 of the tagged crabs (Table 4). U-tags inserted at the abdominal site were retained by 32 of the crabs after one molt. When the data on tag retention were tested with chi-square, the differences were found to be not significant.

Measurements were made to determine if tagging affected the increase in carapace width after one molt. Crabs carrying U-tags at the abdominal or coxal site, and crabs with metal disks in the abdominal site, had an average increase in carapace width after molting of 6.8, 7.3, and 7.7 mm respectively. Control crabs had an average increase in carapace width of 7.6 mm. Crabs with either U-tags or metal disks at the lateral spine site could not be measured after molting because a portion of the carapace had been cut off to insert the tags. An analysis of variance indicated that there were no significant differences in the average growth of tagged and untagged crabs.

DISCUSSION

Various advantages and disadvantages of the tags and insertion sites were observed during the tests. It was easier and quicker to insert U-tags than disk tags, even though U-tags were smaller. The special tool facilitated insertion of U-tags, whereas the forceps used with disk tags were unwieldy. Disk tags caused less damage to the hard exoskeleton of the abdomen because they were inserted between the segments. The blunt, rounded ends of the U-tags sometimes made a small hole in the hard exoskeleton of the abdomen. Infections at the abdominal insertion site were not observed and the wounds were almost invisible after the crabs molted. Less damage was done to the exoskeleton by inserting tags at the abdominal site than by cutting off the lateral spine or causing a crab to autotomize a claw. A U-tag inserted at the coxal site did not rest on or near vital organs, as did tags inserted at the other two sites, but it probably became sealed within the crab during autotomy (Waterman, 1960). Some crabs even regenerated a new claw during these tests. However, the absence of a claw may be a disadvantage to tagged crabs released into a natural population. In consideration of the above, the insertion of a U-tag at the abdominal site was considered the most suitable technique tested.

Table 4. Tagging mortality and tag retention during a test of two types of tags and three insertion sites

Tag site and type		Number of crabs						
		Total Crabs[a]	Pre-molted that		Post-molted that		Post-molted that retained the tag	
			Died	Lived	Died	Lived	Died	Lived
Lateral Spine	Disk	69	29	4	28	8	19	2
	U-tag	72	18	9	39[b]	7	13	4
Abdomen	Disk	72	26	6	31	9	16	3
	U-tag	71	27	3	39	2	30	2
Coxa	U-tag	70	19	2	37	12	24	5[c]
Untagged		70	13	2	31	24		

[a] Less escapement from the holding cages.

[b] Includes one crab that molted twice, retaining the tag on the first but not the second molt.

[c] Three crabs had partially regenerated the claw. The tag was found deep in body tissues.

Adverse holding conditions probably caused many deaths during the tests. Most control mortality occurred after molting and was nearly equal to tagged crab mortality after molting. Most tagging mortalities occurred before molting, particularly during the first two weeks after tagging when very few control deaths occurred. If the mortality of tagged and control crabs is compared at the end of each test, the differences equal 13, 30, and 19%. An average of these differences (20%) was estimated as the magnitude of tagging mortality.

Though tagging mortality was high, U-tags could produce valuable information about Carcinus. Green crab populations are assumed to be fairly discrete, occurring within a localized area such as an estuary, and the recovery of relatively few tagged crabs would serve to support this belief and provide indications of migration patterns. External tags can provide information on migrations (Baptist, Smith and Ropes, 1957; Edwards, 1958), and estimates of longevity (Ropes, 1961), but internal tags have the added feature of providing observations on growth because they are retained through ecdysis.

There is a need for a rapid method of recovering internally tagged crabs, but at present it is only possible to suggest some recovery methods. Dissecting and searching through each crab is one method, but using a device that would detect a tag in the intact crab is more desirable. Moore and Mortimer (1954) have described a metal-sensitive device for fish tags that might be adapted for use with the U-tags, or, if the tags were made radioactive, a radiosensitive device might be used.

ACKNOWLEDGMENT

I gratefully acknowledge the assistance of Mr. Louis D. Stringer, who designed the U-tag inserting tool used in these tests.

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EVOLUTION OF FUR SEAL MANAGEMENT ON THE PRIBILOF ISLANDS

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Restricted in their breeding to the Robben, Commander, and Pribilof Islands, fur seals (Callorhinus ursinus) were twice exploited almost to the point of extinction before positive protection was assured in 1911. That year, Great Britain (for Canada), Japan, Russia, and the United States signed the first of a series of treaties prohibiting pelagic sealing. The treaty ratified in 1957 remains in force today.

Females were first protected in 1835. Lather, the male kill was restricted by limiting salable skins to certain weights or sizes. In the early 1900's, females and males to be reserved for future breeding stock were marked by hot-iron branding to lower their value to pelagic sealers.

Analysis of the kill and counts of live pups from 1912 to 1922 showed that the herd was increasing by 8% annually. The rate of increase was reduced to 7% in 1942 and 6% in 1947. These rates were used to calculate herd growth until it became obvious the population was no longer increasing as supposed. In 1948 the system was abandoned as unrealistic. The average annual kill of 60, 000 young males reached in 1939 did not greatly increase thereafter.

Length classes, which were presumed to correspond to age, were based on the branding of 5, 228 pups in 1912 and subsequent measurements of some of the survivors each year through 1918. Age classification of seals by length was considered accurate until discovery of an aging technique using annual growth layers on the roots of canine teeth. Seals three and four years of age, which make up 80% of the kill, are now shown to overlap considerably within a total length range of from 42 to 48 inches. Under the age-length standards, male seals 41 to 45. 75 inches long were classified as three year-olds and those 46 to 51. 75 as four year-olds. Beginning in 1961, the kill was classified into age groups by determinations from teeth only and length was abandoned as an age indicator.

With revised management policies begun in 1956 the number of breeding females is being reduced to test the hypothesis that a lower population will increase survival and stabilize production. Over 225, 000 females have been taken during the seven-year period. It has also been shown that limited numbers of females can be taken annually, and that skins from females are similar in quality to those from males of like age. The harvest of male seals has been maintained at about 50, 000 annually, and a sustained yield of 15, 000 to 30, 000 females will be a permanent part of the harvest for commercial purposes.

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OBSERVATIONS ON DOLPHINS (*CORYPHAENA* SPP.) IN THE CENTRAL PACIFIC OCEAN.—This note presents some observations made in the central Pacific Ocean on the common dolphin, *Coryphaena hippurus* Linnaeus, and the pompano dolphin, *Coryphaena equiselis* Linnaeus.

The observations were made during a study of the association of fishes with the transitional waters between the North Pacific Central (NPC) and the North Pacific Equatorial (NPE) water types. These transitional waters are called the California Current Extension (CCE). A recent discussion of these water types is given by Seckel (1962, *U. S. Fish Wildl. Serv., Fish. Bull.* 193). The sampling plan called for making 3 longline sets south of the transition zone in the North Pacific Equatorial water type (NPE), 3 in the North Pacific Central water type (NPC), and 3 in the transition zone. This pattern, traversing the CCE, was to be replicated 3 times, giving a total of 27 longline stations; unfortunately, owing to rough seas, only 6 stations could be occupied in NPC, so in all, 24 stations were fished. A preliminary report of the results of this fishing has been published (1963, *Comm. Fish. Rev.* 25(5):25–26).

The presence of dolphins at longline stations was noted either by observing them just below the surface during daily periods of 4–5 hr of continuous observation, or by catching them on the longline or on pole and line. In addition to the well-known morphological differences between the species, freshly caught adult *C. hippurus* and *C. equiselis* also exhibited striking color differences. Although *C. hippurus* underwent its usual striking color changes, a yellow suffusion remained evident on the head, lower lateral portions of the body, and lower lobe of the caudal fin, whereas *C. equiselis* has very little yellow coloration and, in general, is a uniform steely blue. While observed in the water, *C. equiselis* was distinguished easily from *C. hippurus* by its deeper body and its lack of what appeared in *C. hippurus* as a yellow caudal fin. This color difference was verified repeatedly by the capture of observed fish on hook and line.

Observations of the dolphins were made from the underwater viewing chamber of the research vessel Charles H. Gilbert, and on one occasion a banded color pattern was seen on a presumably adult *C. equiselis* by one of our field party (Gary H. Miller). This pattern, probably an ephemeral response to feeding, has been noted in several species and has been described in *C. hippurus* by several authors (Gibbs and Collette 1959, *Bull. Mar. Sci. Gulf Carib.* 9(2): 122; Strasburg and Marr 1961, *Copeia* 1961 (2):226–228).

Common dolphins were taken or observed at all but 2 stations, both in the CCE; at these 2 stations *C. equiselis* were taken. Pompano dolphins were taken or observed at 3 of the 6 NPC stations and at 7 of the 9 CCE stations. There was no evidence of the presence of pompano dolphins at any of the 9 stations fished in the NPE. Although the numbers of *C. equiselis* captured or observed were not large, the replicated nature of the observations suggests that it occurred only in the NPC and CCE water types. The observations further suggest that the pompano dolphin may be more abundant in the CCE than in the NPC. These observations do not rule out the possibility that *C. equiselis* may have been present in the NPE but could not be observed or caught by our methods. Whether the stratified distribution of *C. equiselis* is due to variables associated with latitude or to possible ecotonal influences of the boundary requires further study.

Meristic counts of anal rays (ray = spine or soft ray), dorsal rays, lateral-line scales, and gill rakers were made according to Hubbs and Lagler (1958, Fishes of the Great Lakes Region, *Cranbrook Inst. Sci. Bull.* 26) and are presented in Table 1. These data permit several contrasts with those reported by other authors. Counts of dorsal rays, anal rays, and gill-raker elements of *C. equiselis* of the Philippine area by Herre and Herald (1951, *Philippine J. Sci.* 79(3):327) are modally the same as our central Pacific data. Uchida (1935, *Bull. Jap. Soc. Sci. Fish.* 4(4):226) gave meristic data on several *C. equiselis* from Japan which are insufficient for comparison.

Gibbs and Collette (*op. cit.*:126–127) gave meristic counts on western Atlantic specimens of *C. hippurus* and *C. equiselis*, the latter mostly young and juveniles. Their counts will be compared with counts from

Table 1. Frequency Distribution of Dorsal Rays, Anal Rays, Gill Rakers on Lower Limb of First Arch, and Lateral-Line Scales by Five Scale Classes for *Coryphaena equiselis* and *Coryphaena hippurus* Taken in the Central Pacific Ocean, January and February 1963.

Species	Dorsal rays													
	49	50	51	52	53	54	55	56	57	58	59	60	61	62
C. equiselis	1	–	9	11	13	9	8	1	–	1	–	–	–	–
C. hippurus	–	–	–	–	–	3	5	11	18	12	15	10	7	1

	Anal rays							
	22	23	24	25	26	27	28	29
C. equiselis	2	–	10	21	16	3	1	–
C. hippurus	–	–	3	14	27	23	13	2

	Gill rakers				
	7	8	9	10	11
C. equiselis	–	1	7	34	11
C. hippurus	3	32	42	3	–

	Lateral-line scales																											
	161–165	166–170	171–175	176–180	181–185	186–190	191–195	196–200	201–205	206–210	211–215	216–220	221–225	226–230	231–235	236–240	241–245	246–250	251–255	256–260	261–265	266–270	271–275	276–280	281–285	286–290	291–295	296–300
C. equiselis	2	4	6	14	7	8	9	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
C. hippurus	–	–	–	–	–	–	–	–	–	–	1	1	–	–	5	8	4	8	5	14	7	5	10	5	3	4	–	1

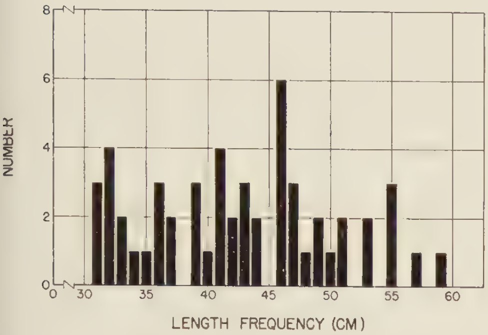

Fig. 1. Length–frequency distribution (FL) of 53 *C. equiselis* taken in central Pacific, January–February 1963.

our specimens. Dorsal rays of the western Atlantic and central Pacific samples of *C. equiselis* were modally the same. The modal number of anal rays for the Pacific specimens is one less than for the western Atlantic specimens. In central Pacific specimens the modal number of gill rakers is one greater than for the western Atlantic data. Differences in gill raker counts between central Pacific specimens and the western Atlantic data would be accentuated if the number of gill rakers were reduced with age, since the central Pacific counts were made only on adult fish. It also appears that the central Pacific samples of *C. equiselis* have fewer lateral-line scales than the western Atlantic specimens.

In *C. hippurus,* dorsal rays for the Pacific specimens appear to be fewer than for the western Atlantic data. Anal rays for the Pacific specimens are also modally 1 fewer than for the western Atlantic specimens. The modal number of gill rakers is 1 greater for the central Pacific than for the Atlantic samples. The high variability in counts of lateral-line scales makes comparisons difficult.

The size range of *C. equiselis* has not been reported except that they are generally smaller than *C. hippurus.* Uchida (*op. cit.*:224), in his English synopsis, reported that "the ordinary size of the fish landed is ca. 60 cm in length and 800∼1,000 g. in weight." He also stated that *C. equiselis* may attain a weight of 2,500 g. Jordan (1907, Fishes. Henry Holt, N. Y., p. 502) noted that "*Coryphaena equiselis* rarely exceeds 2-1/2 feet." The fork lengths of our specimens of *C. equiselis* (Fig. 1) range between 308 and 587 mm.

Adult *C. hippurus* usually are thought to be piscivorous, feeding particularly on exocoetids (see, however, Gibbs and Collette, *op. cit.*:145–149). Stomach contents of 91 *C. hippurus* were examined. The results confirm that the common dolphin is piscivorous and takes exocoetids. Flying fish not only were the most numerous organisms in the stomach, but they also comprised a large portion of the total volume of stomach contents. Other important food items were gempylids and penaeid shrimps.

Nothing has been reported previously of the food habits of *C. equiselis.* The stomach contents of 53 individuals were examined. It should be noted that 39 of the 53 fish examined were from the same relatively large school, and consequently their stomach contents may not be representative. Bramids were the most common item in the stomachs of the pompano dolphin. In contrast to the common dolphin, exocoetids were not a common item in the diet of this species.

It has been surmised that feeding in *C. hippurus* is inhibited at night (Gibbs and Collette, *op. cit.*:149). On several occasions *C. hippurus* was observed chasing flying fish at night-light stations, and often this species was caught on hook and line from large schools that swam around the vessel as it drifted at night. On some occasions night-feeding by *C. hippurus* was observed when the water was brightly illuminated, but on other occasions there was evidence of feeding when the only source of artificial illumination was the dim running lights of the vessel. Stomachs of *C. hippurus* caught at night were examined. Several contained large, presumably freshly ingested myctophids. It seems probable that dolphin feed actively on bright moonlit nights. This supplies a speculative example of a mechanism by which elements of bathypelagic fauna contribute to the food web of epipelagic forms.

The observations reported in this note were made on the "Boundary I" cruise of the Charles H. Gilbert, research vessel of the Bureau of Commercial Fisheries Biological Laboratory at Honolulu. I wish to thank Mr. Gary H. Miller and Captain William Tanaka for their assistance in collecting specimens. Thanks are also due Frederick H. Berry for his comments.—Brian J. Rothschild, *Bureau of Commercial Fisheries, Biological Laboratory, Honolulu, Hawaii.*

21. SKIPJACK TUNA OCEANOGRAPHY

The broad concepts of fisheries oceanography are discussed in the context of studies on the skipjack tuna *(Katsuwonus pelamis)*. Fisheries oceanography relates the study of fisheries with features of the oceanic environment.

In essence, fisheries science is an investigation of the harvest or yield of an exploited species. An attempt is made to maximize catch while minimizing the cost of fishing on a sustained basis. In order to regulate maximized catches and minimized costs, the components of yield must be investigated. By some models these components are recruitment, growth, natural mortality, and fishing mortality. An additional factor, availability, is of utmost importance in considering yields of tropical tunas.

Fisheries oceanography attempts to relate the components of yield with features of the oceanic environment. Some of these features are currents, winds, temperature, salinity, and productivity.

Our studies of the skipjack tuna are at a stage where we are defining our units of study. These units are groups of skipjack which differ from one another in life history attributes. For example skipjack spawn mostly in the northern winter in Marquesan waters, but in Hawaiian waters these fish spawn mostly in the northern summer. Some of these groups may be genetically distinct and are called subpopulations.

In order to study these units we have developed a model which for the first time formulates a working hypothesis to evaluate the origin and movements of exploited groups of skipjack in the eastern and central Pacific Ocean.

The principal features of this model follow:

1. Skipjack exploited in the eastern Pacific fishery consist of large numbers of fish which originate in the equatorial central Pacific.
2. The exit of skipjack from the area of the eastern Pacific fishery is associated with a spawning movement toward the central Pacific.
3. Skipjack taken in the Hawaii fishery include fish of both Hawaiian and equatorial origins.

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U. S. Bureau of Commercial Fisheries

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THE SHRIMP *TRACHYPENEUS SIMILIS* IN TAMPA BAY

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THE SHRIMP *TRACHYPENEUS SIMILIS* IN TAMPA BAY

Carl H. Saloman

During a faunal sampling project in Florida estuarine waters, several species of shrimp were captured along with other crustaceans and fishes. Shrimp were particularly numerous at two sampling stations during the period August 1961 through December 1963. Both stations were in the Tampa Bay system: one in Old Tampa Bay and the other at Egmont Key located at the mouth of the Bay. Each of these two stations was occupied for 24-hour periods alternately in consecutive months from August 1962 through December 1963. Forty-nine other stations in Tampa Bay and one station offshore were sampled from August 1961 through December 1963 during daylight hours only. Types of gear used in the daylight studies were trawls, beach seines, and push nets. Trawls were the only gear used during the 24-hour studies.

Numerous specimens of penaeid shrimp were caught during the 24-hour biological studies conducted on the east side of Egmont Key at the mouth of Tampa Bay. The dominant penaeid shrimp present was *Panaeus duorarum* (Burkenroad), along with some *Trachypeneus constrictus* (Stimpson) and *Sicyonia typica* (Boeck). Also present were 97 specimens of *Trachypeneus similis* (Smith). These are the first specimens reported from Tampa Bay and the west coast of Florida between Apalachicola Bay and the Tortugas grounds. All 97 specimens were caught during darkness with either a 10- or 16-foot shrimp try net. No *T. similis* were caught in our regular daylight sampling of Tampa Bay or in 24-hour sampling in Old Tampa Bay. Data recorded relative to the occurrence of *T. similis* were size, sex, temperature, and salinity (table 1).

The station at Egmont Key is characterized by a sandy shell bottom, a depth of approximately two fathoms of water, and an abundant growth of *Thallasia testudinum* (Konig) and *Syringodium* filiforme (Kutz).

Discussion

The month of December was the period of maximum abundance of *T. similis* at the Egmont Key station with 95 of 97 total specimens being caught during that time. Eldred (1959a) found that

the period of maximum abundance of *T. similis* on the Tortugas grounds was from January through March 1959 and stated that *T. similis* is next in abundance to *P. duorarum* on the Tortugas grounds, where both species are harvested in the commercial fishery. Similarly, Eldred (1959b) and Ingle, Eldred, Jones, and Hutton (1959) found that the major abundance of *T. similis* occurred on the Tortugas grounds from January through April 1958.

TABLE 1

Data for *Trachypeneus similis* from Egmont Key, Florida

Date	Time of Capture	Number and Sex	Carapace Length mm.	Bottom Temperature °C	Bottom Salinity o/oo
8-31-62	0300	1 ♀	8.7	30.30	32.97
10-30-62	0300	1 ♀	9.4	21.32	31.58
12-20-62	2100	2 ♂	9.3 (8.9-9.6)	14.40	32.99
12-12-63	2000	5 ♂	7.2 (6.4-7.5)	16.12	33.71
		10 ♀	9.7 (6.6-12.2)		
12-12-63	2300	13 ♂	8.6 (7.5-9.6)	16.14	33.80
		32 ♀	10.2 (7.5-12.4)		
12-13-63	0200	4 ♂	8.0 (6.0-9.3)	16.37	33.75
		17 ♀	9.8 (6.3-12.2)		
12-13-63	0500	6 ♂	8.3 (7.3-8.9)	16.21	33.44
		6 ♀	8.8 (7.2-10.3)		
Total		30 ♂	8.26 (6.0-9.6)		
		67 ♀	9.85 (6.3-12.4)		

Females averaged larger than males in each of our collections containing both sexes. Ingle, Eldred, Jones, and Hutton (1959) also found that the females were larger than the males in all the monthly summaries of their catch records on the Tortugas grounds.

All specimens from Egmont Key were found in salinities exceeding 31 parts per thousand.

Burkenroad (1934) reported the distribution of *T. similis* from the Gulf of Mexico, northern Antilles, Venezuela, Louisiana, and the western coast of Florida. He stated, however, that *T. constrictus* inhabits areas north and east of that of *T. similis*. He also stated that the latter replaces *T. constrictus* on the western and southern shores of the Gulf of Mexico and the Caribbean.

The occurrence of *T. similis* throughout the Gulf of Mexico is mentioned by various authors. Eldred (1959a, 1959b) and Ingle, Eldred, Jones, and Hutton (1959) cited the occurrence of *T. similis* on the Tortugas grounds. Perez-Farfante (1953) mentioned that it occurred in the Bahia de Cienfuegos of Cuba. Hildebrand (1954) in his study of the fauna of the brown shrimp (*Penaeus aztecus* Ives) grounds in the western Gulf of Mexico found that it was second to *P. aztecus* in abundance. He also noted that *T. similis* was uncommon in depths of less than 12 fathoms and appeared to prefer a mud bottom. Guest (1956) mentioned that *T. similis* occurs in bays and the Gulf of Mexico along the Texas coast. Renfro and Brusher (1963) in their work on shrimp populations between Galveston, Texas, and Cameron, Louisiana, found the majority of *T. similis* occurring in 7½ and 15 fathoms, but some in depths as great as 45 fathoms. Burkenroad (1939) listed the species as occurring in Pensacola Bay, Florida, and stated that it is a frequently encountered species west of 88° 10′ in the Gulf of Mexico. He also found that *T. similis* appeared to prefer a muddy bottom. Wass (1955) did not mention its occurrence in his samples from Alligator Harbor and adjacent inshore areas of northwestern Florida but stated that it is known to occur off the coast of northwestern Florida within the 30-fathom line.

The omission of this species from several papers on the fauna of the Gulf waters of Florida is notable. In a bait shrimp survey of the west coast of Florida Woodburn, Eldred, Clark, Hutton, and Engle (1957) did not mention the occurrence of *T. similis.* When reporting on the pink shrimp, *Penaeus duorarum,* in Florida waters, Eldred, Ingle, Woodburn, Hutton, and Jones (1961) did not list this species. *T. similis* was also absent from the lists of Hutton, Eldred, Woodburn, and Ingle (1956), reporting on a study of the ecology of Boca Ceiga Bay, Florida. Eldred (personal communication) found this species only on the Tortugas grounds and in Pensacola and Apalachicola Bays on the west coast of Florida. Published research results by Tabb and Manning (1961) from northern Florida Bay and by Tabb, Dubrow, and Jones (1962) from Everglades National Park, Florida, did not mention the occurrence of *T. similis.* Nevertheless, the record of *T. similis* from Tampa Bay now shows that its distribution probably extends throughout the entire periphery of the Gulf of Mexico.

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Supplement
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Sources of Limnological and Oceanographic Apparatus and Supplies.
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TO
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SPECIAL PUBLICATION NO. 1

(Third Revision)

Sources of Limnological and Oceanographic Apparatus and Supplies

Prepared by
The Committee on Apparatus and Supplies
American Society of Limnology and Oceanography, Inc.
April 1964

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PREFACE

This edition of Special Publication No. 1 has three parts, the first two of which are similar in content to those used in the previous revision (J. H. Ryther, C. S. Yentsch, and G. H. Lauff, LIMNOLOGY AND OCEANOGRAPHY, 4: 357–365). In the first part, Apparatus and Supplies, under the alphabetically arranged headings and subheadings appear the names of the firms which manufacture or distribute the particular item of apparatus or supply. The second part, List of Firms, gives the names and address of the firms in alphabetical order. The third part, Supplemental Source Material, contains information on other sources, lists and publications which may be helpful in identifying equipment and locating sources of supply.

The fields of limnology and oceanography are presently undergoing rapid expansion. At the same time, the instruments and equipment used in the fields are greatly increasing in number, diversification, and capability. Of particular importance is the development and application of reliable and accurate electronic instrumentation. As this growth proceeds, small companies devoted to instrumentation in limnology and oceanography are being formed and more large corporations are entering certain fields of instrumentation and instrument systems.

In launching upon its task, the committee compiled a list of 220 items of apparatus and supplies which was sent to over 700 firms in the United States and abroad. Information was requested on the manufacture of listed items and on additional items for inclusion in the list. The present list was prepared from the replies. We regret that it was not feasible to recanvass the firms regarding added items and some questions of nomenclature, thus some omissions and errors undoubtedly occur.

As in previous editions, the committee attempted to limit the list mainly to items which find particular use in limnology and oceanography and are not normally found in general scientific supply house catalogs. Meteorological instruments are generally omitted except for those which find specific application, such as radiation meters used in light or productivity studies. Large data recording and processing systems and their components, such as amplifiers, tape recorders, etc., which are widely advertised in computer and electronic equipment publications, are generally omitted. Costly limited-use oceanographic instrument systems, such as those built primarily for the military services, are also generally omitted.

A comparison of the number of entries in the 1959 and in the present editions may be of interest as an indication of the growth in the field:

Edition:	*1959*	*1964*
No. of Items	131	313 (Exclusive of cross references)
No. of Firms	157	308
Entries in List of A&S	455	2,012

The committee wishes to express its thanks to the many firms that responded to its inquiries, to A.S.L.O. members who sent information regarding sources of apparatus and supplies, and to Dr. George H. Lauff for his advice as *ex-officio* member of the committee. We are indebted to Dr. Livia Tonolli and Miss Miriam A. Jameson for their assistance, and particularly to Mrs. Harriet Tobey for preparation of questionnaires and typing of the final manuscript.

LIST OF APPARATUS AND SUPPLIES

A

1. AIR CURTAINS
   - Hinde Engineering
2. AIRBORNE RADIATION THERMOMETER
   - Barnes Engineering
3. ALGAL CULTURES (see 27.a)
4. AMBIENT NOISE MEASURING SYSTEM (see 126.d)
5. AMBIENT WATER BATH (respiration studies)
   - Alpine Geophysical
   - A. Gallenkamp
   - Hydro-Bios Apparatebau
   - Ogawa Seiki
   - Research Manufacturing
   - Rigosha
6. ANCHOR, STIMSON DEEP-SEA, SHORT SCOPE
   - Ocean Research Equipment
7. ANEMOMETER, HAND-HELD
   - Hydro Products
8. ANTIFOULING PROTECTION
   - Hydro Products
   - Oceanographic Industries

B

9. BALL BREAKER (see 12.c)
10. BATHYTHERMOGRAPH
    - a. *Chart recording*
      - Askania-Werke
      - Braincon
      - Hydro-Bios Apparatebau
      - Hytech
      - Marine Advisers
    - b. *Electronic* (see also 82.q)
      - Alpine Geophysical
      - Bendix, Bendix-Pacific Div.
      - Braincon
      - Dalmo Victor
      - Hydro Products
      - Hytech
      - Imperial Thermal Systems
      - Marine Acoustical Services
      - Marine Advisers
      - Northrop Nortronics
      - Ramsay Engineering
    - c. *Expendable*
      - General Motors, Defense Research Labs.
      - Hydro Products
      - Sparton Electronics
    - d. *Sea sampler—BT* (see 133.q)
    - e. *Standard*
      - Alpine Geophysical
      - Belfort Instrument
      - S. G. Brown
      - Dittmore–Freimuth
      - Kahl Scientific Instrument
      - Mashpriborintorg
      - Ogawa Seiki
      - Rigosha
      - Wallace & Tiernan
11. BATHYTHERMOGRAPH SLIDES
    - a. *Metallic coated*
      - Hytech
    - b. *Smoked*
      - S. G. Brown
      - Hydro-Bios Apparatebau
      - Kahl Scientific Instrument
      - Ogawa Seiki
      - Rigosha
      - Tsurumi-Seiki Kosakusho
      - Wallace & Tiernan
12. BOTTOM DETECTORS OR INDICATORS FOR INSTRUMENTS
    - a. *Acoustic pinger, relative position*
      - Edgerton, Germeshausen & Grier
      - Ocean Research Equipment
    - b. *Audio signal device, bottom contact*
      - Ramsay Engineering
    - c. *Ball breaker*
      - Alpine Geophysical
      - Geraldines Laboratories
      - Hydro-Bios Apparatebau
      - Ogawa Seiki
      - Rigosha
      - Tsurumi-Seiki Kosakusho
13. BOTTOM SAMPLER AND DREDGES (see also 22)
    - a. *Bacterial sampler*
      - Gulton Industries, Marine Instrument Dept.
      - Kahl Scientific Instrument
      - Hydro Products
      - Rigosha
    - b. *Binley silt sampler*
      - S. Smith & Sons (England)
    - c. *Biological dredges*
      - Alpine Geophysical
      - General Biological Supply House
      - Kurt Gohla
      - Hydro Products
      - Hydro-Bios Apparatebau
      - Kahl Scientific Instrument
      - C. M. Murray Instrument
      - Ogawa Seiki
      - Rigosha
      - Tsurumi-Seiki Kosakusho
      - Wildlife Supply
      - Dr. H. Züllig, Apparatebau
    - d. *Birge–Ekman dredge*
      - Beak & Egger
      - Hans Büchi
      - General Engineering & Scientific
      - Kurt Gohla
      - Hydro-Bios Apparatebau
      - Kahl Scientific Instrument
      - Ogawa Seiki
      - Rigosha
      - Wildlife Supply
      - Dr. H. Züllig, Apparatebau

13. Bottom sampler and dredges (contd.)
    e. *Clamshell bucket*
        Alpine Geophysical
        General Engineering & Scientific
        Geraldines Laboratories
        Marine Exploration
        Mashpriborintorg
        National Steel & Shipbuilding
        Rigosha
        Wildlife Supply
    f. *Dutch grab*
        S. Smith & Sons (England)
        Wildlife Supply
    g. *F.B.A. automatic mud sampler*
        Freshwater Biological Association
    h. *Jenkins surface mud sampler*
        Freshwater Biological Association
        S. Smith & Sons (England)
    i. *Kemmerer*
        Beak & Egger
    j. *Knudsen*
        Alpine Geophysical
        Kahl Scientific Instrument
        Laboratoire Océanographique
        S. Smith & Sons (England)
    k. *Lenz*
        Kurt Gohla
        Hydro-Bios Apparatebau
        Hydrowerkstätten
    l. *Ooze sucker*
        General Engineering & Scientific
        Mashpriborintorg
    m. *Orange peel bucket*
        Alpine Geophysical
        Geraldines Laboratories
        Hytech
        Kahl Scientific Instrument
        Marine Exploration
        National Steel & Shipbuilding
    n. *Pettersson dredge*
        Beak & Egger
        Bergen Nautik
        Kurt Gohla
        Geraldines Laboratories
        Kahl Scientific Instrument
        Laboratoire Océanographique
        Wildlife Supply
    o. *Ruttner mud-surface*
        Kurt Gohla
    p. *Shipek sampler*
        Hydro Products
    q. *Snapper*
        Alpine Geophysical
        General Engineering & Scientific
        Kahl Scientific Instrument
        Ogawa Seiki
        Rigosha
        Submarine Cables
        Tsurumi-Seiki Kosakusho
    r. *Surber*
        Beak & Egger
        Wildlife Supply
    s. *Underway sampler or Scoopfish*
        Alpine Geophysical
        Askania-Werke
        Hydrowerkstätten
        Kahl Scientific Instrument
        Mashpriborintorg
        Mécabolier
        Rigosha
    t. *Van Veen or Petersen grab*
        Geraldines Laboratories
        Kurt Gohla
        Hydro-Bios Apparatebau
        Hydrowerkstätten
        Laboratoire Océanographique
        "Thalassia" di Dario Pagan
    u. *Other*
        Elliott & Garrood
        Rigosha

14. BUOY OR BUOY SYSTEMS (see also 44)
    a. *Accessories: lights, radar targets, etc.*
        Airtronics
        Alpine Geophysical
        Astropower
        Braincon
        Edgerton, Germeshausen & Grier
        Roberto Galeazzi
        General Scientific
        Geodyne
        Goodyear Aircraft
        Hydro Products
        Hytech
        Martin, Electronic S & P Div.
        Ocean Research Equipment
        Oceanic Instruments
        Rayflex Exploration
        Republic Aviation
        Rigosha
        Sea Space Systems
        Submarine Cables
        Triton Marine Products
        Vitro
        Wallace & Tiernan
    b. *Anchored, marker or reference*
        Airtronics
        Alpine Geophysical
        Astropower
        Braincon
        Clevite Ordnance
        Daystrom
        Edo
        General Dynamics/Electronics
        Geodyne
        Geraldines Laboratories
        Goodyear Aircraft
        Hydro Products
        Martin, Electronic S & P Div.
        Ocean Research Equipment
        Ocean Science & Engineering
        Rayflex Exploration Development
        Sea Space Systems
        Specialty Electronics
        Triton Marine Products
        Wallace & Tiernan

14. Buoy or buoy systems (contd.)
  c. *Beacons: radio, radar or acoustic* (see also 126.c)
    - Airtronics
    - Alpine Geophysical
    - Astropower
    - Bendix, Bendix-Pacific Div.
    - Braincon
    - Clevite Ordnance
    - Concord Control
    - Edo
    - General Dynamics/Electronics
    - General Electric, HMED
    - General Scientific
    - Geodyne
    - Gulton Industries, Marine Instrument Dept.
    - Hastings–Raydist
    - Hydro Products
    - Hytech
    - Instrument Systems, Telephonics Div.
    - ITT Federal Laboratories
    - Ocean Research Equipment
    - Oceanic Instruments
    - Prodelin
    - RADCOM
    - Republic Aviation
    - Research Manufacturing
    - Sea Space Systems
    - Straza Industries
    - Triton Marine Products
    - Vitro
  d. *Drifting*
    - Airtronics
    - Astropower
    - Braincon
    - Edo
    - Geodyne
    - Hytech
    - Hydro Products
    - Ocean Research Equipment
    - Oceanic Instruments
    - Republic Aviation
    - Rayflex Exploration
    - Sea Space Systems
  e. *Instrumented for observations*
    - Airtronics
    - Alpine Geophysical
    - Astropower
    - Bendix, Bendix-Pacific Div.
    - Braincon
    - Century Electronics & Instruments
    - Clevite Ordnance
    - Concord Control
    - Daystrom
    - Edo
    - General Dynamics/Electronics
    - General Electric, HMED
    - Geodyne
    - Goodyear Aircraft
    - Gulton Industries, Marine Instrument Div.
    - Hastings–Raydist
    - Honeywell, Seattle Development Laboratory
    - Hydro Products
    - Hydro-Space Technology
    - Hytech
    - Instrument Systems, Telephonics Div.
    - Marine Advisers
    - Martin, Electronic S & P Div.
    - Ocean Research Equipment
    - Oceanic Instruments
    - Pratt & Whitney
    - RADCOM
    - Republic Aviation
    - Sea Space Systems
    - S. Smith & Sons (England)
    - Specialty Electronics Development
  f. *Time delay, pop-up*
    - Alpine Geophysical
    - Braincon
    - Geodyne
    - Hydro Products
    - Kahl Scientific Instrument
    - Ocean Research Equipment
    - Sea Space Systems

C

15. CABLE
  a. *Marine electric, general*
    - Ansonia Wire & Cable
    - Boston Insulated Wire & Cable
    - Braincon
    - Kahl Scientific Instrument
    - Hydro Products
    - Hytech
    - Joy Manufacturing
    - Marsh & Marine Manufacturing
    - Research Manufacturing
  b. *Neutrally buoyant, electric*
    - Superior Cable

16. CABLE ACCESSORIES
  e. *Electric swivels*
    - Alpine Geophysical
    - Electro-Mechanical Research
    - Hydro Products
    - Hytech
    - Marine Advisers
    - Oceanic Instruments
  b. *Fairing*
    - Braincon
    - Commercial Engineering
  c. *Fairing for chain*
    - Commercial Engineering
    - Goodyear Aircraft
  d. *Watertight connectors, cable or bulkhead*
    - Clevite Ordnance
    - Electro-Mechanical Research
    - Electro-Oceanics
    - Hydro Products
    - Joy Manufacturing
    - Marsh & Marine Manufacturing

17. CAMERAS AND ACCESSORIES
    a. *Deep-sea*
        - Alpine Geophysical
        - Braincon
        - Edgerton, Germeshausen & Grier
        - Hydro Products
        - Kahl Scientific Instrument
        - M & E Marine Supply
        - Marine Advisers
        - National Marine Consultants
        - Northridge Research
        - Oceanic Instruments
        - Pratt & Whitney
        - Traid
        - United Aircraft, Norden Div.
        - Vare Industries
        - Videonics
    b. *Hand-held and shallow water*
        - Alfa American
        - American Diving Equipment
        - Braincon
        - Burleigh Brooks
        - Century Engineers
        - Dart Aircraft
        - Di-Conex
        - Diving Corp. of America
        - Dotsom–Kimes
        - Edgerton, Germeshausen & Grier
        - Farrand Optical
        - Fenjohn
        - Healthways of Los Angeles
        - Mako Products
        - Northridge Research
        - E. E. Peterson
        - Pratt & Whitney
        - Sampson Machine Works
        - Seahawk Products
        - United Aircraft, Norden Div.
        - U.S. Divers
        - Vare Industries
        - Videonics

18. CARBON-14
    a. *Carbonate ampoules for productivity studies*
        - Kahl Scientific Instrument
        - International Agency for Carbon-14 Determination
        - Tracerlab
    b. *Collecting apparatus, aquatic*
        - General Biological Supply House
        - International Agency for Carbon-14 Determination
        - Kahl Scientific Instrument
        - Membranfiltergesellschaft
        - Oceanic Instruments
        - Tsurumi-Seiki Kosakusho
    c. *Collecting apparatus, atmospheric*
        - Membranfiltergesellschaft
    d. *Determination of Carbon-14 activity* (see 92.a)
    e. *Kit for Carbon-14 and chlorophyll measurements*
        - Kahl Scientific Instrument
        - Ocean Research Equipment
        - Plankton Research Instruments

19. CASES OR INSTRUMENT CAPSULES (see also 115)
    - Alpine Geophysical
    - Braincon
    - Concord Control
    - Geodyne
    - Hydro Products
    - Ocean Research Equipment

20. CHLOROPHYLL KIT (see 18.e)

21. COMPUTING OR ANALYSIS AIDS
    a. *Automatic chart reader*
        - Geotechnical
    b. *Culbertson oceanographic slide rule*
        - Kahl Scientific Instrument
    c. *Digital X–Y plotters*
        - Benson–Lehner
        - Gerber Scientific
    d. *Knudsen's tables*
        - Kurt Gohla
        - Hydro Products
        - Kahl Scientific Instrument
        - Laboratoire Océanographique
        - Ogawa Seiki
    e. *LaFond tables* (H.O. Pub. No. 614)
        - U.S. Naval Oceanographic Office
    f. *Oxygen saturation slide rule*
        - Dr. R. Burkard

22. CORERS
    a. *Drill*
        - Alpine Geophysical
        - Feldmann Engineering & Mfg.
        - Pratt & Whitney
        - Sprague & Henwood
    b. *Gravity*
        - Alpine Geophysical
        - Askania-Werke
        - General Engineering & Scientific
        - Geraldines Laboratories
        - Hydro-Bios Apparatebau
        - Hydrowerkstätten
        - Hydro Products
        - Hytech
        - Kahl Scientific Instrument
        - Mashpriborintorg
        - Mécabolier
        - Ogawa Seiki
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        - Tsurumi-Seiki Kosakusho
        - Dr. H. Züllig, Apparatebau
    c. *Piston*
        - Alpine Geophysical
        - Geraldines Laboratories
        - General Engineering & Scientific
        - Hydro Products
        - Kahl Scientific Instrument
        - Ocean Research Equipment
        - Ogawa Seiki
        - Rigosha
        - Sprague & Henwood
        - Tsurumi-Seiki Kosakusho
        - Dr. H. Züllig, Apparatebau

23. CORING ACCESSORIES
    - a. *Core catchers*
        - Alpine Geophysical
        - Geraldines Laboratories
        - Kahl Scientific Instrument
        - Ogawa Seiki
        - Rigosha
        - Tsurumi-Seiki Kosakusho
    - b. *Plastic liners*
        - Alpine Geophysical
        - Hydro Products
        - Kahl Scientific Instrument
        - Rigosha
        - Tsurumi-Seiki Kosakusho
        - Dr. H. Züllig, Apparatebau

24. COUNTER, PARTICLE SIZE
        - Coulter Electronics
        - Honeywell, Industrial Products
        - SANSAR

25. COUNTING CELLS, PLANKTON
    - a. *Kolkwitz*
        - Hans Büchi
        - Kurt Gohla
        - Hydro-Bios Apparatebau
        - Dr. H. Züllig, Apparatebau
    - b. *Palmer*
        - Aloe Scientific
    - c. *Sedgwick–Rafter*
        - Aloe Scientific
        - Hellige
        - Wildlife Supply
    - d. *Sedimentation tubes*
        - Aloe Scientific
        - Askania-Werke
        - Hans Büchi
        - Rigosha
        - "Thalassia" di Dario Pagan

26. CRAB CALIPER
        - Oceanic Instruments
        - C. M. Murray Instrument

27. CULTURES
    - a. *Algae*
        - Botany School, Culture Collection of Algae and Protozoa
        - Centre de Recherches Hydrobiologiques du C.N.R.S.
        - General Biological Supply House
        - General Dynamics Electric Boat
        - Laboratoire de Cryptogamie du Muséum
        - Ward's Natural Science Establishment
        - Woods Hole Oceanographic Institution
    - b. *Protozoa*
        - Botany School, Culture Collection of Algae and Protozoa
        - Centre de Recherches Hydrobiologiques du C.N.R.S.

28. CURRENT METERS AND MEASURING DEVICES
    - a. *Acoustic flowmeter*
        - Marine Laboratories
        - Società Italiana Apparecchi Precisione
        - Westinghouse Defense Products
    - b. *Bifilar*
        - Askania-Werke
        - Mashpriborintorg
    - c. *Boehnecke*
        - Askania-Werke
    - d. *Carruthers*
        - Elliott & Garrood
    - e. *Current drag*
        - Geodyne
        - Marine Advisers
        - National Marine Consultants
        - Rigosha
    - f. *Direct reading magnetic*
        - W. & L. E. Gurley
        - S. Smith & Sons (England)
    - g. *Ducted impeller*
        - Hydro Products
        - Kahl Scientific Instrument
        - Marine Advisers
        - Ogawa Seiki
    - h. *Ekman*
        - Bergen Nautik
        - Elliott & Garrood
        - Kahl Scientific Instrument
        - Mashpriborintorg
        - Ogawa Seiki
        - Rigosha
        - S. Smith & Sons (England)
        - "Thalassia" di Dario Pagan
        - Tsurumi-Seiki Kosakusho
    - i. *Film recording*
        - Hydrowerkstätten
    - j. *Fjeldstad*
        - Bergen Nautik
        - Kahl Scientific Instrument
    - k. *Geomagnetic* (GEK)
        - Ocean Research Equipment
        - Mashpriborintorg
        - Sperry Piedmont
    - l. *Jacobsen*
        - Laboratoire Océanographique
    - m. *Paddle wheel*
        - Hydrowerkstätten
        - Mashpriborintorg
    - n. *Price*
        - W. & L. E. Gurley
        - Kahl Scientific Instrument
        - Ogawa Seiki
        - Rigosha
        - Tsurumi-Seiki Kosakusho
    - o. *Richardson*
        - Braincon
        - Geodyne
        - Hydro Products
    - p. *Roberts*
        - Hydro Products
        - Marine Advisers
        - S. Smith & Sons (England)
    - q. *Savonius rotor*
        - Braincon
        - Hydro Products

28. Current meters, measuring devices (contd.)
    - Hytech
    - General Dynamics/Electronics
    - Marine Advisers
    - Sea Space Systems
  - r. *Ship log*
    - RADCOM
  - s. *Stevens midget*
    - Leupold & Stevens
  - t. *Turbulence meter, 3-dimensional*
    - Oceanic Instruments
  - u. *Turbulence meter, Venturi, one-dimensional*
    - Aerojet-General
  - v. *Woodhead seabed drifter*
    - Geodyne
  - w. *Other*
    - Beckman Instruments
    - Di-Conex
    - General Dynamics/Electronics
    - Gulton Industries, Marine Instrument Dept.
    - Mashpriborintorg
    - Mécabolier
    - National Marine Consultants
    - Neyrpic
    - Ogawa Seiki
    - A. Ott
    - Pratt & Whitney
    - Sea Space Systems
    - Triton Marine Products
    - Tsurumi-Seiki Kosakusho

D

29. DEPRESSOR
    - Astropower
    - Braincon
    - Geodyne
    - Hydro Products
    - Kahl Scientific Instrument
    - C. M. Murray Instrument
    - Ocean Research Equipment
    - Ogawa Seiki
    - PneumoDynamics
    - Rayflex Exploration
    - Rigosha
    - Fred Schueler
    - Tsurumi-Seiki Kosakusho
30. DIVING EQUIPMENT AND ACCESSORIES
  - a. *Attached (helmet or suit)*
    - Craftsweld Equipment
    - Diving Equipment & Supply
    - Roberto Galeazzi
    - General Biological Supply House
    - M & E Marine Supply
    - Morse Diving Equipment
  - b. *Self-contained (SCUBA)*
    - American Diving Equipment
    - Craftsweld Equipment
    - Dacor
    - Diving Corp. of America
    - Diving Equipment & Supply
    - Garrett
    - Healthways of Los Angeles
    - M & E Marine Supply
    - Mako Products
    - Marine Exploration
    - Mar-Mac Industries
    - Rose Aviation
    - U.A.S.–Divemaster
    - U.S. Divers

E

31. ECHO SOUNDER (see 82.f)
32. ELECTRIC CABLE AND ACCESSORIES (see 15, 16)
33. ELECTRODES (see 91)

F

34. FISH ANESTHETIC
    - Sandoz
35. FISH-FINDER SONAR (see 126.k)
36. FISH MEASURING BOARDS AND DEVICES
    - Braincon
    - Laboratoire Océanographique
    - C. M. Murray Instrument
    - Oceanic Instruments
    - Ogawa Seiki
    - Rigosha
    - Fred Schueler
    - Wildlife Supply
37. FISH REACTION TIMER
    - Oceanic Instruments
38. FISH SCALE EMBEDDING PLASTIC
    - General Biological Supply House
    - Ogawa Seiki
    - Ward's Natural Science Establishment
    - Wildlife Supply
39. FISH SCALE PRESS
    - Wildlife Supply
40. FISH SCALE PROJECTOR
    - Flatters & Garnett
    - Ogawa Seiki
41. FISH SCALE READER
    - Geodyne
    - Oceanic Instruments
    - Ogawa Seiki
42. FISH SHOCKER OR ELECTRIC FISHING EQUIPMENT
    - Electro-Mechanical Research
    - Elin–Union
    - Oceanic Instruments
    - Ogawa Seiki
    - Pikes Peak Electronics
43. FISH STAMINA TESTER
    - Oceanic Instruments
44. FLOATS AND BUOYANT DEVICES (see also 14)
  - a. *Fish net floats*
    - Consolidated Net & Twine
    - Dale Plastics
    - Fish Net & Twine
    - Geodyne
    - Marinovich Trawl
    - Ogawa Seiki

44. Floats and buoyant devices (contd.)
    - Rigosha
    - A. M. Starr Net
  - b. *Flexible rubber and fluid filled*
    - U.S. Rubber
  - c. *Submersible, air or pressurized-gas filled*
    - Hydro Products
    - Lithium
  - d. *Submersible, foam filled*
    - Geodyne
    - Hydro Products
  - e. *Submersible, lithium filled*
    - Lithium

45. FLOWMETERS FOR NETS
    - Alpine Geophysical
    - Bergen Nautik
    - Braincon
    - Giannini Controls
    - Hydro Products
    - Hydro-Bios Apparatebau
    - Kahl Scientific Instrument
    - Laboratoire Océanographique
    - C. M. Murray Instrument
    - Ogawa Seiki
    - Rigosha
    - Fred Schueler
    - "Thalassia" di Dario Pagan
    - Tsurumi-Seiki Kosakusho

46. FOREL COLOR SET
    - Hydro-Bios Apparatebau
    - Kahl Scientific Instrument
    - Mashpriborintorg
    - Rigosha
    - Tsurumi-Seiki Kosakusho

G

47. GAS ANALYZER
  - a. *Atmospheric CO_2*
    - Baird & Tatlock (London)
    - Beckman Instruments
    - Consolidated Electrodynamics
    - Consolidated Systems
    - R. L. Faley & Associates
    - Farrand Optical
    - Kurt Gohla
    - Honeywell, Industrial Products
    - Leeds & Northrup
    - Marine Advisers
    - Ogawa Seiki
  - b. *Gases in solution*
    - Aloe Scientific
    - Baird & Tatlock (London)
    - Beckman Instruments
    - Consolidated Electrodynamics
    - R. L. Faley & Associates
    - Farrand Optical
    - A. Gallenkamp
    - Kurt Gohla
    - Hellige
    - Marine Advisers
    - Mark
    - Ogawa Seiki
    - Rayflex Exploration
    - Rigosha

48. GEOLOGICAL STRATIFICATION RECORDER (see 82.g)

49. GRAVIMETER, SHIPBOARD
    - Askania-Werke
    - Borg–Warner Controls
    - General Electric, HMED
    - General Precision, Kearfott Div.
    - LaCoste & Romberg
    - Mandrel Industries

H

50. HYDROLOGIC OPTICS
  - a. *Beam transmissometer (hydrophotometer)*
    - Askania-Werke
    - Farrand Optical
    - General Engineering & Scientific
    - Hellige
    - Hydro Products
    - Hydrowerkstätten
    - Hytech
    - Kahl Scientific Instrument
    - Marine Advisers
    - Oceanic Instruments
    - Philip Schenk
    - Fred Schueler
    - Vare Industries
  - b. *Irradiance meter*
    - Hoffman Electronics
    - Hydro Products
    - Kahl Scientific Instrument
    - Marine Advisers
    - OPTOmechanisms
    - Plankton Research Instruments
    - Rigosha
    - Fred Schueler
    - Tsurumi-Seiki Kosakusho
  - c. *Laboratory nephelometer, high sensitivity*
    - G. K. Turner
  - d. *Scattering meter*
    - Hellige
    - Hydro Products

51. HYDROMETER
    - Baird & Tatlock (London)
    - A. Gallenkamp
    - Kurt Gohla
    - Hydro-Bios Apparatebau
    - Kahl Scientific Instrument
    - Ogawa Seiki
    - Rigosha
    - Società Italiana Apparecchi Precisione
    - Tsurumi-Seiki Kosakusho
    - Watanabe Keiki Manufacturing
    - Yoshino Keiki
    - G. H. Zeal

52. HYDROPHONES (see 126.h)

53. HYDROPHOTOMETER (see 50.a)

I

54. Ice corers and drills, powered portable
    - Feldmann Engineering & Mfg.
55. Incubators, special for photosynthetic studies
    - Plankton Research Institute

K

56. Knudsen burettes and pipettes
    - General Engineering & Scientific
    - Kurt Gohla
    - Hydro Products
    - Hydro-Bios Apparatebau
    - Kahl Scientific Instrument
    - Macalaster Scientific
    - Ogawa Seiki
    - Rigosha
    - Watanabe Keiki Manufacturing
57. Knudsen's tables (see 21.d)

L

58. Light meters (see 50)
59. Limnigraph (see 112)
60. Limnological apparatus and gear, general
    - Beak & Egger

M

61. Magnetometer, marine
    - Alpine Geophysical
    - Braincon
    - S. G. Brown
    - Hewlett–Packard
    - HRB–Singer
    - Instrument Systems, Telephonics Div.
    - Varian
62. Mobile sea floor instrument platform, remote control
    - Hydro Products
63. Molecular filters
    - Gelman Instrument
    - International Agency for Carbon-14 Determination
    - Membranfiltergesellschaft
    - Rigosha
    - Carl Schleicher & Schuell
64. Molecular filtration apparatus
    - A. Gallenkamp
    - Gelman Instrument
    - International Agency for Carbon-14 Determination
    - Membranfiltergesellschaft
    - Carl Schleicher & Schuell
    - Tobler, Ernst & Traber
65. Mud penetrometer (see 94.b)

N

66. Navigation systems and equipment
    - a. *Acoustic navigation equipment*
        - Research Manufacturing
    - b. *Decca hyperbolic navigation system*
        - Decca Navigator
    - c. *Electronic position indicator*
        - Alpine Geophysical
        - Bendix, Bendix-Pacific Div.
        - General Dynamics/Electronics
        - Geodyne
        - Hastings–Raydist
        - National Marine Consultants
        - Northrop Nortronics
        - Polarad Electronics
        - RADCOM
        - Rayflex Exploration
        - Sea Space Systems
    - d. *Hi-Fix (high resolution, short range, for small boats)*
        - Decca Navigator
    - e. *HYDRODIST*
        - Alpine Geophysical
        - Tellurometer
    - f. *Inertial systems*
        - Autonetics
    - g. *LORAC*
        - SEISCOR
    - h. *LORAN*
        - Concord Control
        - Edo
        - Polarad Electronics
        - Sperry Piedmont
        - Triton Marine Products
    - i. *Radar ranging unit*
        - Alpine Geophysical
        - Anritsu Electronic Works
    - j. *SHORAN*
        - Polarad Electronics
    - k. *Track plotters*
        - Alpine Geophysical
        - Clevite Ordnance
67. Nets and netting
    - a. *Apstein closing*
        - Consolidated Net & Twine
        - Kurt Gohla
        - Hydro-bios Apparatebau
        - Laboratoire Océanographique
        - Puget Sound Workshop
        - Rigosha
        - "Thalassia" di Dario Pagan
    - b. *Birge closing*
        - Consolidated Net & Twine
        - Hydro-Bios Apparatebau
        - Kahl Scientific Instrument
        - Rigosha
    - c. *Bobbinet and cable net*
        - Consolidated Net & Twine
        - General Biological Supply House
        - Glotex Importers
        - Hydro-Bios Apparatebau
        - Marinovich Trawl
        - Puget Sound Workshop
        - William C. Schroeder
    - d. *Bolting cloth, silk or nylon*
        - Paul O. Abbe
        - Consolidated Net & Twine

67. Nets and netting (contd.)
    - General Biological Supply House
    - Glotex Importers
    - Great Western Manufacturing
    - Hydro-Bios Apparatebau
    - Kahl Scientific Instrument
    - Kressilk Products
    - Laboratoire Océanographique
    - Puget Sound Workshop
    - Rigosha
    - William C. Schroeder
    - Fred Schueler
    - SAATI
    - Schweiz. Seidengazefabrik
    - John Stanier
    - Tobler, Ernst & Traber
    - Ward's Natural Science Establishment
    - Wildlife Supply
  - e. *Fish nets*
    - Consolidated Net & Twine
    - Dominion Textile
    - General Biological Supply House
    - Glotex Importers
    - Puget Sound Workshop
    - Rigosha
    - A. M. Starr Net
    - Ward's Natural Science Establishment
  - f. *Hand collecting net*
    - Freshwater Biological Association
  - g. *Hensen*
    - Consolidated Net & Twine
    - Hydro-Bios Apparatebau
    - Kahl Scientific Instrument
    - Laboratoire Océanographique
    - Mécabolier
    - Puget Sound Workshop
    - William C. Schroeder
    - Fred Schueler
    - "Thalassia" di Dario Pagan
  - h. *Larval fish net*
    - Consolidated Net & Twine
    - Fish Net & Twine
    - Glotex Importers
    - Hydro-Bios Apparatebau
    - Rigosha
    - William C. Schroeder
    - Fred Schueler
  - i. *Mid-water trawl* (see 119)
  - j. *Monofilament*
    - Consolidated Net & Twine
    - Glotex Importers
    - Great Western Manufacturing
    - Rigosha
    - William C. Schroeder
    - Fred Schueler
    - Tobler, Ernst & Traber
    - Wildlife Supply
  - k. *Plankton* (see also 75)
    - Alpine Geophysical
    - Braincon
    - Hans Büchi
    - Ernest Case
    - Consolidated Net & Twine
    - Flatters & Garnett
    - Freshwater Biological Association
    - General Engineering & Scientific
    - Glotex Importers
    - Kurt Gohla
    - Hydro-Bios Apparatebau
    - Hytech
    - Kahl Scientific Instrument
    - Kressilk Products
    - Laboratoire Océanographique
    - C. M. Murray Instrument
    - Ogawa Seiki
    - Puget Sound Workshop
    - Rigosha
    - William C. Schroeder
    - Fred Schueler
    - "Thalassia" di Dario Pagan
    - Tobler, Ernst & Traber
    - Tsurumi-Seiki Kosakusho
    - Ward's Natural Science Establishment
    - Wildlife Supply
    - Dr. H. Züllig, Apparatebau
  - l. *Specialty synthetic twines* (see 125)
  - m. *Stramin nets*
    - Consolidated Net & Twine
    - Fish Net & Twine
    - Hydro-Bios Apparatebau
    - Laboratoire Océanographique
  - n. *Stramin netting*
    - Consolidated Net & Twine
    - Fish Net & Twine
    - Hydro-Bios Apparatebau
    - Laboratoire Océanographique
    - SAATI

O

68. OCEANOGRAPHIC GEAR AND EQUIPMENT, GENERAL
    - Alpine Geophysical
    - Astropower
    - Bergen Nautik
    - Hans Büchi
    - Elliott & Garrood
    - A. Gallenkamp
    - General Engineering & Scientific
    - Geraldines Laboratories
    - Kurt Gohla
    - Gulton Industries, Marine Instrument Dept.
    - Hydro Products
    - Hydro-Bios Apparatebau
    - Hydrowerkstätten
    - Hytech
    - Kahl Scientific Instrument
    - Laboratoire Océanographique
    - Mashpriborintorg
    - Mécabolier
    - C. M. Murray Instrument
    - Negretti & Zambra
    - Ogawa Seiki
    - Rigosha
    - Fred Schueler
    - "Thalassia" di Dario Pagan

68. Oceanographic gear, equipment (contd.)
    Tsurumi-Seiki Kosakusho
    Wildlife Supply
    Dr. H. Züllig, Apparatebau

P

69. Peat sampler, Ruttner
    Kurt Gohla

70. Photometers, underwater (see 50)

71. Plankton net buckets and rings
    Alpine Geophysical
    Bergen Nautik
    Hans Büchi
    Ernest Case
    Elliott & Garrood
    Kurt Gohla
    Hydro Products
    Hydro-Bios Apparatebau
    Kahl Scientific Instrument
    Marinovich Trawl
    Mécabolier
    C. M. Murray Instrument
    Ogawa Seiki
    Puget Sound Workshop
    Rigosha
    Fred Schueler
    Wildlife Supply
    Dr. H. Züllig, Apparatebau

72. Plankton net closing device
    Plankton Research Instruments

73. Plankton nets (see 67.k)

74. Plankton sample splitters
    Oceanic Instruments
    Ocean Research Equipment
    Rigosha

75. Plankton samplers (see also 67.k)
  a. *Bé, multiple*
    Alpine Geophysical
    Kahl Scientific Instrument
  b. *Clarke–Bumpus*
    Ernest Case
    Kurt Gohla
    Kahl Scientific Instrument
    C. M. Murray
    Puget Sound Workshop
    Rigosha
    Fred Schueler
  c. *Hardy plankton recorder*
    Kahl Scientific Instrument
    Ogawa Seiki
    Scottish Marine Biological Association
  d. *High-speed plankton sampler*
    Braincon
    Ernest Case
    Castle Industries
    Elliott & Garrood
    Hydro-Bios Apparatebau
    Kahl Scientific Instrument
    Oceanic Instruments
    Rigosha
    Fred Schueler
  e. *Juday trap*
    Kahl Scientific Instrument
    Rigosha
  f. *Multiple, preset automatic, submarine mounted*
    Commercial Engineering
  g. *Opening–closing, remote control*
    General Motors, Defense Research Laboratories
  h. *Plankton pump*
    Kurt Gohla
    Hydro Products
    Oceanic Instruments
    Ogawa Seiki

76. Power units
  a. *Batteries, rechargeable, submersible*
    Ramsay Engineering
  b. *Bio-batteries*
    General Scientific
  c. *Power plant, portable*
    Hydro Products

77. Pressure housings or cases (see 19)

78. Probes (see 91)

79. Productivity kit (see 18.e)

80. Pycnometers
    Beckman Instruments
    A. Gallenkamp
    Kurt Gohla
    Hydro-Bios Apparatebau
    Ogawa Seike
    Rigosha

R

81. Radiometer, atmospheric
  a. *Infrared*
    Barnes Engineering
  b. *Net exchange*
    Beckman & Whitley
    Kahl Scientific Instrument
  c. *Short wave or solar (pyrheliometer)*
    Eppley Laboratory
    Farrand Optical
    Kahl Scientific Instrument
    P. J. Kipp & Zonen
    Northrop Nortronics
  d. *Total (short and long wave) hemispheric*
    Beckman & Whitley
    P. J. Kipp & Zonen

82. Recording or indicating instruments, *in situ* measurement
  a. *Bathythermograph* (see 10)
  b. *Conductivity, freshwater, portable*
    Braincon
    Century Electronics & Instruments
    Elcontrol
    Honeywell, Industrial Products
    Hydro Products
    Hydro-Bios Apparatebau
    Hytech
    Industrial Instruments
    Kahl Scientific Instrument

82. Recording instruments, *in situ* (contd.)
    - Oceanic Instruments
    - Ogawa Seiki
  - c. *Conductivity–temperature–depth*
    - Braincon
    - Dittmore–Freimuth
    - Fisher Research
    - Foxboro
    - Geodyne
    - Gulton Industries, Marine Instrument Dept.
    - Hellige
    - Hydro Products
    - Hytech
    - Industrial Instruments
    - Kahl Scientific Instrument
    - Kieler Howaldtswerke
    - Leeds & Northrup
    - Oceanic Instruments
    - Pratt & Whitney
    - Dr. H. Züllig, Apparatebau
  - d. *Depth (pressure)*
    - Alpine Geophysical
    - S. G. Brown
    - Baldwin–Lima–Hamilton, Electronics Div.
    - Braincon
    - Colvin Laboratories
    - Electroacustic
    - Fisher Research
    - Foxboro
    - Geodyne
    - Giannini Controls
    - Gulton Industries, Marine Instrument Dept.
    - Hydro Products
    - Hytech
    - Marine Acoustical Services
    - Marine Advisers
    - Negretti & Zambra
    - Oceanic Instruments
    - Ramsay Engineering
    - Sea Space Systems
    - Simonsen Radio
    - S. Smith & Sons (England)
    - Tsurumi-Seiki Kosakusho
  - e. *Depth–time, self-contained*
    - Alpine Geophysical
    - Benthos
    - Braincon
    - Century Electronics & Instruments
    - Edgerton, Germeshausen & Grier
    - Geodyne
    - Hydro Products
    - Kahl Scientific Instrument
    - Leupold & Stevens
    - Marine Advisers
    - Ogawa Seiki
    - Pratt & Whitney
    - RADCOM
    - Raytheon
    - Sea Space Systems
    - Simonsen Radio
    - Straza Industries
  - f. *Echo sounders*
    - Bendix, Bendix-Pacific Div.
    - S. G. Brown
    - Clevite Ordnance
    - Construction Aggregates
    - Daystrom
    - Danforth/White
    - Di-Conex
    - Edgerton, Germeshausen & Grier
    - Edo
    - Electroacustic
    - Fletcher Aviation
    - General Electric, HMED
    - General Instrument, Harris ASW Div.
    - General Precision, Kearfott Div.
    - Geraldines Laboratories
    - Instrument Systems, Telephonics Div.
    - M & E Marine Supply
    - Marine Exploration
    - Ocean Research Equipment
    - Rayflex Exploration
    - Raytheon
    - Research Manufacturing
    - Ross Laboratories
    - Simonsen Radio
    - S. Smith & Sons (England)
    - Straza Industries
    - Triton Marine Products
  - g. *Geological stratification recorder*
    - Alpine Geophysical
    - Clevite Ordnance
    - Instrument Systems, Telephonics Div.
    - Rayflex Exploration
  - h. *Maximum depth, self-contained*
    - Benthos
  - i. *Oxygen*
    - Baird & Tatlock (London)
    - Beckman Instruments
    - Bristol
    - Gelman Instrument
    - Hays
    - Honeywell, Industrial Products
    - Hydro-Bios Apparatebau
    - Hydro Products
    - Jarrell–Ash
    - Oceanic Instruments
    - Southern Analytical
    - Yellow Springs Instrument
  - j. *Oxygen-temperature*
    - Yellow Springs Instrument
  - k. *pH*
    - Beckman Instruments
    - Bristol
    - Foxboro
    - A. Gallenkamp
    - Gelman Instrument
    - Honeywell, Industrial Products
    - Hydro-Bios Apparatebau
    - Kahl Scientific Instrument
    - Oceanic Instruments
    - Ogawa Seiki
    - Rigosha

82. Recording instruments, *in situ* (contd.)
  - l. *Precision depth recorder (for echo sounders)*
    - Alpine Geophysical
    - RADCOM
  - m. *Salinity (direct reading)*
    - Beckman Instruments
    - Braincon
    - Dittmore–Freimuth
    - Foxboro
    - Geodyne
    - Hydro Products
    - Hytech
    - Industrial Instruments
    - Pratt & Whitney
    - Sea Space Systems
  - n. *Salinity–temperature–depth*
    - Hydro Products
    - Hytech
  - o. *Sound velocity*
    - ACF Industries
    - Aloe Scientific
    - Alpine Geophysical
    - Cohu Electronics, Massa Div.
    - Daystrom
    - Dyna-Empire
    - Geraldines Laboratories
    - Gulton Industries, Marine Instrument Dept.
    - Hytech
    - Ogawa Seiki
    - Ramsay Engineering
    - Rayflex Exploration
  - p. *Sound velocity–temperature–depth*
    - Ramsay Engineering
  - q. *Temperature–depth* (see also 10)
    - Alpine Geophysical
    - Applied Research Associates
    - Askania-Werke
    - Astropower
    - Baldwin–Lima–Hamilton, Electronics Div.
    - Bendix, Bendix-Pacific Div.
    - Braincon
    - Bristol
    - S. G. Brown
    - Robert M. Crosby
    - Dittmore–Freimuth
    - Foxboro
    - Geodyne
    - Kurt Gohla
    - Gulton Industries, Marine Instrument Dept.
    - Honeywell, Seattle Development Laboratory
    - Hytech
    - Imperial Thermal Systems
    - Leeds & Northrup
    - Marine Acoustical Services
    - Marine Advisers
    - Mécabolier
    - Negretti & Zambra
    - Oceanic Instruments
    - Olympic Instruments
    - Pratt & Whitney
    - Ramsay Engineering
    - Sea Space Systems
    - Società Italiana Apparecchi Precisione
    - Specialty Electronics Development
  - r. *Temperature–oxygen–time, aquatic*
    - Oceanic Instruments
  - s. *Temperature – pressure – time, self-contained*
    - Oceanic Instruments
  - t. *Thermograph or temperature*
    - Alpine Geophysical
    - Applied Research Associates of Texas
    - Astropower
    - Baldwin–Lima–Hamilton, Electronics Div.
    - Barber Colman
    - Bendix, Friez Instrument Div.
    - Braincon
    - Bristol
    - S. G. Brown
    - Hans Büchi
    - Compagnie Générale de Metrologie-Metrix
    - Robert M. Crosby
    - Dittmore–Freimuth
    - Farrand Optical
    - Foxboro
    - Gelman Instrument
    - Geodyne
    - Giannini Controls
    - Kurt Gohla
    - Gulton Industries, Marine Instrument Dept.
    - Hays
    - Honeywell, Industrial Products
    - Honeywell, Seattle Development Laboratory
    - Hydro Products
    - Hytech
    - Imperial Thermal Systems
    - Kahl Scientific Instrument
    - Leeds & Northrup
    - Marine Advisers
    - Mécabolier
    - F. L. Moseley
    - Negretti & Zambra
    - Oceanic Instruments
    - Ogawa Seiki
    - Pratt & Whitney
    - Ramsay Engineering
    - Rigosha
    - Sea Space Systems
    - Società Italiana Apparecchi Precisione
    - Specialty Electronics Development
    - Tsurumi-Seiki Kosakusho
    - Westinghouse Defense Products
    - G. H. Zeal
    - Dr. H. Züllig, Apparatebau
  - u. *Thermograph, Self-contained*
    - Aloe Scientific
    - Alpine Geophysical
    - Foxboro
    - Geodyne

82. Recording instruments, *in situ* (contd.)
    Hydro Products
    Marine Advisers
    Ogawa Seiki
  v. *Thermoprobe, sea floor*
    Alpine Geophysical
    Imperial Thermal Systems
    Specialty Electronics Development
  w. *Tide* (see 112)
  x. *Wave* (see 134–136)

83. RESPIROMETERS AND RESPIRATORY APPARATUS
    Gulton Industries, Marine Instrument Dept.
    Mark
    Plankton Research Instruments
    Yellow Springs Instrument

84. RHODAMINE-B (CHEMICAL)
    Hellige
    Hydro Products

85. RHODAMINE-B DETECTOR (FLUOROMETER)
    Oceanic Instruments
    PneumoDynamics
    G. K. Turner

86. ROTENONE AND AQUATIC WEED CONTROL MATERIALS
    Chemical Insecticide
    S. B. Penick

87. ROUSSELET COMPRESSOR
    Flatters & Garnett

S

88. SALINOMETERS
    Atlantic Research
    Braincon
    Beckman Instruments
    A. Gallenkamp
    Geodyne
    Kurt Gohla
    Hellige
    Hydro Products
    Hytech
    Industrial Instruments
    Instrument Manufacturing Corp. of So. Africa
    Kahl Scientific Instrument
    Oceanic Instruments
    Ogawa Seiki
    Pratt & Whitney
    Rigosha
    Tellurometer
    Tsurumi-Seiki Kosakusho
    G. H. Zeal

89. SCREENS AND SCREENING
  a. *Grit gauze*
    Paul O. Abbe
    Hans Büchi
    Consolidated Net & Twine
    Great Western Manufacturing
    Kressilk Products
    Newark Wire Cloth
    Fred Schueler
    Schweiz. Seidengazefabrik
    Tobler, Ernst & Traber
  b. *Wire screening*
    General Biological Supply House
    Great Western Manufacturing
    C. O. Jelliff Manufacturing
    Kressilk Products
    Newark Wire Cloth
    Fred Schueler
    Tobler, Ernst & Traber
    W. S. Tyler
  c. *Wire sieves*
    A. Gallenkamp
    General Biological Supply House
    Great Western Manufacturing
    Hydro-Bios Apparatebau
    Kressilk Products
    Newark Wire Cloth
    Rigosha
    Tobler, Ernst & Traber
    Tsurumi-Seiki Kosakusho
    W. S. Tyler
    Ward's Natural Science Establishment

90. SEDIMENT PROFILE RECORDER OR SEISMIC PROFILER (see 82.g)

91. SENSORS OR TRANSDUCERS, ELECTRICAL OUTPUT
  a. *Conductivity electrodes*
    Bristol
    Dittmore–Freimuth
    Elcontrol
    Foxboro
    Hellige
    Honeywell, Industrial Products
    Hydro Products
    Industrial Instruments
    Kahl Scientific Instrument
    Leeds & Northrup
    Mandrel Industries
    Oceanic Instruments
    Pratt & Whitney
    Radiation Systems
    Dr. H. Züllig, Apparatebau
  b. *Conductivity toroid*
    Daystrom
    Hydro Products
    Hytech
    Industrial Instruments
    Oceanic Instruments
    Radiation Systems
  c. *Current direction*
    Braincon
    Di-Conex
    Flow
    General Dynamics/Electronics
    General Electric, HMED
    Geodyne
    Gulton Industries, Marine Instrument Dept.
    Hydro Products
    Hydro-Bios Apparatebau
    Hytech
    Marine Advisers

91. Sensors or transducers, electrical (contd.)
    - Northrop Nortronics
    - Oceanic Instruments
    - Ogawa Seiki
    - Pratt & Whitney
    - RADCOM
    - Sea Space Systems
    - Westinghouse Defense Products

d. *Current speed*
    - Braincon
    - Daystrom
    - Di-Conex
    - Flow
    - General Dynamics/Electronics
    - General Electric, HMED
    - General Scientific
    - Geodyne
    - Giannini Controls
    - Gulton Industries, Marine Instrument Dept.
    - Hydro Products
    - Hytech
    - Kahl Scientific Instrument
    - Marine Advisers
    - Northrop Nortronics
    - Oceanic Instruments
    - Ogawa Seiki
    - RADCOM
    - Sea Space Systems
    - Società Italiana Apparecchi Precisione
    - Triton Marine Products
    - Westinghouse Defense Products

e. *Inclinometer or attitude*
    - Airtronics
    - Bendix, Friez Instrument Div.
    - Braincon
    - Geodyne
    - Giannini Controls
    - Gulton Industries, Marine Instrument Dept.
    - Hastings–Raydist
    - Pratt & Whitney
    - Servonic

f. *Liquid level*
    - Bendix, Bendix-Pacific Div.
    - Braincon
    - Bristol
    - Di-Conex
    - Elcontrol
    - Foxboro
    - Gems
    - Gulton Industries, Marine Instrument Dept.
    - Honeywell, Industrial Products
    - Hydro Products
    - Hytech
    - Kahl Scientific Instrument
    - Trans-Sonics

g. *Load cells* (see 106)

h. *Oxygen electrode*
    - Beckman Instruments
    - Gelman Instruments
    - Hays
    - Hellige
    - Honeywell, Industrial Products
    - Jarrell–Ash
    - Oceanic Instruments
    - Southern Analytical
    - Yellow Springs Instrument
    - Dr. H. Züllig, Apparatebau

i. *Oxidation–reduction potential electrode*
    - Beckman Instruments
    - Century Electronics & Instr.
    - Hellige
    - Honeywell, Industrial Products
    - Kahl Scientific Instrument
    - Leeds & Northrup
    - Oceanic Instruments

j. *pH electrode*
    - Aloe Scientific
    - Beckman Instruments
    - Brinkman Instruments
    - Bristol
    - Foxboro
    - Honeywell, Industrial Products
    - Kahl Scientific Instrument
    - Leeds & Northrup
    - Oceanic Instruments
    - Ogawa Seiki
    - Rigosha

k. *Pressure (depth)*
    - Baldwin–Lima–Hamilton, Electronics Div.
    - Borg–Warner Controls
    - Braincon
    - S. G. Brown
    - Cohu Electronics, Massa Div.
    - Colvin Laboratories
    - Daystrom
    - Di-Conex
    - Dittmore–Freimuth
    - General Electric, HMED
    - Giannini Controls
    - Gulton Industries, Marine Instrument Dept.
    - Hydro Products
    - Hytech
    - Instrument Systems, Telephonics Div.
    - Marine Advisers
    - Oceanic Instruments
    - Pratt & Whitney
    - Ramsay Engineering
    - Sea Space Systems
    - Servonic
    - Specialty Electronics Development
    - Sperry Piedmont
    - Trans-Sonics
    - Westinghouse Defense Products

l. *Pressure variation, high precision* (see also 91.r)
    - Baldwin–Lima–Hamilton, Electronics Div.
    - Bendix, Bendix-Pacific Div.
    - Bendix, Friez Instrument Div.
    - Braincon
    - Century Electronics & Instruments
    - Consolidated Electrodynamics
    - Di-Conex

91. Sensors or transducers, electrical (contd.)
    - General Electric, HMED
    - Gulton Industries, Marine Instrument Dept.
    - Hastings–Raydist
    - Hytech
    - Instrument Systems, Telephonics Div.
    - Oceanic Instruments
    - Pratt & Whitney
    - Rayflex Exploration
    - Rigosha
    - Sea Space Systems
    - Dr. H. Züllig, Apparatebau

  m. *Self-scrubbing electrodes for electrochemical measurements*
    - Oceanic Instruments

  n. *Sound velocity*
    - Lockheed Electronics
    - Ramsay Engineering

  o. *Temperature, interchangeable thermistor probes*
    - Yellow Springs Instrument

  p. *Temperature, thermistor*
    - Applied Research Associates
    - Bendix, Friez Instrument Div.
    - Braincon
    - Di-Conex
    - Dittmore–Freimuth
    - Electro-Oceanics
    - Fenwal Electronics
    - Foxboro
    - General Electric, HMED
    - Giannini Controls
    - Gulton Industries, Marine Instrument Dept.
    - Honeywell, Industrial Products
    - Honeywell, Seattle Development Laboratory
    - HRB-Singer
    - Hydro Products
    - Imperial Thermal
    - Jarrell–Ash
    - Kahl Scientific Instrument
    - Marine Advisers
    - Marsh & Marine Manufacturing
    - Oceanic Instruments
    - Ogawa Seiki
    - Radiation Systems
    - Ramsay Engineering
    - Rigosha
    - Sea Space Systems
    - Sparton Electronics
    - Specialty Electronics Instrument
    - Yellow Springs Instrument
    - Dr. H. Züllig, Apparatebau

  q. *Temperature, other*
    - Baldwin–Lima–Hamilton, Electronics Div.
    - Braincon
    - Bristol
    - Danforth/White
    - Daystrom
    - Dittmore–Freimuth
    - Farrand Optical
    - Foxboro
    - Gelman Instrument
    - Gulton Industries, Marine Instrument Dept.
    - Hays
    - Honeywell, Industrial Products
    - Hydro Products
    - Kahl Scientific Instrument
    - Leeds & Northrup
    - Marine Advisers
    - Marsh & Marine Manufacturing
    - Negretti & Zambra
    - Oceanic Instruments
    - Ogawa Seiki
    - Pratt & Whitney
    - Ramsay Engineering
    - Rigosha
    - Sea Space Systems
    - Specialty Electronics Development
    - Trans-Sonics
    - Westinghouse Defense Products

  r. *Vibration pressure transducer* (see also 91.1)
    - Consolidated Electrodynamics

92. SERVICES

  a. *Determinations of Carbon-14 activity*
    - Hydro Products
    - International Agency for Carbon-14 Determination
    - New England Nuclear
    - Nuclear Chicago
    - Rigosha
    - SANSAR

  b. *Equipment tests at sea*
    - Ocean Research Equipment

  c. *Film reading and data processing*
    - Geodyne

  d. *Gamma ray spectroscopy*
    - Robert A. Taft Sanitary Engineering Center

  e. *Pressure test facility*
    - Ocean Research Equipment
    - Società Italiana Apparecchi Precisione

  f. *Ships, charter or lease*
    - Aerojet-General
    - Alpine Geophysical
    - Astropower
    - Clevite Ordnance
    - Consolidated Net & Twine
    - Daystrom
    - Geraldines Laboratories
    - Honeywell, Seattle Development Laboratory
    - Marine Acoustical Services
    - Marine Exploration
    - Perry Submarine Builders
    - State Boat
    - U.S. Underseas Cable

  g. *Thermometer calibration*
    - Bergen Nautik
    - Kurt Gohla

92. Services (contd.)
    - Gulton Industries, Marine Instrument Dept.
    - HRB-Singer
    - Imperial Thermal Systems
    - Kahl Scientific Instrument
    - Leeds & Northrup
    - Negretti & Zambra
    - Ogawa Seiki
    - Philadelphia Thermometer
    - Società Italiana Apparecchi Precisione
    - Trans-Sonics
    - Watanabe Keiki Manufacturing
    - Woods Hole Oceanographic Institution
  - h. *Underwater acoustic calibration*
    - Clevite Ordnance
    - Macalaster Scientific

93. Sludge detector
    - Elcontrol

94. Soil mechanics equipment
  - a. *Dill–Moore vane shear meter*
    - Hydro Products
  - b. *Mud penetrometer*
    - Rigosha
  - c. *Soil bearing meter, expendable*
    - General Motors, Defense Research Laboratories

95. Sparker (see 82.g)

96. Splitters, plankton sample (see 74)

97. Standard sea water
    - Hydro Products
    - Kahl Scientific Instrument
    - Laboratoire Océanographique
    - Ogawa Seiki
    - Rigosha

98. Stempel pipette
    - Aloe Scientific
    - Hans Büchi
    - General Engineering & Scientific
    - Kurt Gohla
    - Hydro-Bios Apparatebau
    - Laboratoire Océanographique
    - Rigosha

99. Sterile sample bags
    - Hydro Products

100. Submersible vehicles, manned
  - a. *Free flooding for SCUBA divers*
    - Aerojet-General
  - b. *Pressurized*
    - American Submarine
    - Roberto Galeazzi
    - General Dynamics/Electric Boat
    - Geraldines Laboratories
    - International Underwater Research
    - Perry Submarine Builders
    - Republic Aviation
    - Vare Industries
    - Westinghouse Defense Products

101. Swallow float (see 126.n)

T

102. Tags, fish
  - a. *Acoustic*
    - Straza Industries
  - b. *Fluorescent*
    - Oceanic Instruments
  - c. *Metallic*
    - Bergen Nautik
    - California Eastern Engineering
    - Inst. de Investigaciones Pesqueras
    - National Band & Tag
    - Oceanic Instruments
    - Rigosha
    - Salt Lake Stamp
  - d. *Plastic*
    - Bergen Nautik
    - National Band & Tag
    - Oceanic Instruments
    - Rigosha
    - Salt Lake Stamp
  - e. *Radioactive*
    - Oceanic Instruments
    - Tracerlab

103. Tags, lobster, seal, and walrus
    - Bergen Nautik
    - Ketchum Manufacturing Sales
    - National Band & Tag
    - Oceanic Instruments
    - Salt Lake Stamp

104. Television, closed circuit, underwater
    - American Submarine
    - Ampex
    - Bendix, Bendix-Pacific Div.
    - Bludworth Marine
    - Clevite Ordnance
    - Cohu Electronics, Kin Tel Div.
    - Farrand Optical
    - General Electric, HMED
    - Hydro Products
    - Marine Advisers
    - Oceanic Instruments
    - Pratt & Whitney
    - Pye T.V.T. Ltd.
    - Vare Industries
    - Videonics

105. Television, tape recorder, portable
    - Ampex
    - Precision Instrument

106. Tensiometers or load cells
    - Baldwin–Lima–Hamilton, Electronics Div.
    - Braincon
    - Castle Industries
    - W. C. Dillon
    - Goodyear Aircraft
    - Ogawa Seiki

107. Thermograph (see 82.t)

108. Thermometer frames, reversing
    - Bergen Nautik
    - Hans Büchi
    - Kurt Gohla
    - Hydro Products

8. Thermometer frames, reversing (contd.)
    Hydro-Bios Apparatebau
    Hydrowerkstätten
    Kahl Scientific Instrument
    Laboratoire Océanographique
    Mécabolier
    C. M. Murray
    Negretti & Zambra
    Ogawa Seiki
    Rigosha
    Società Italiana Apparecchi Precisione
    "Thalassia" di Dario Pagan
    Tsurumi-Seiki Kosakusho
    Watanabe Keiki Manufacturing
    Wildlife Supply

9. THERMOMETER, RADIATION (see 2, 81.a)

0. THERMOMETERS, REVERSING (PROTECTED AND UNPROTECTED)
    Askania-Werke
    Bergen Nautik
    Hans Büchi
    Kurt Gohla
    Kahl Scientific Instrument
    Hydro-Bios Apparatebau
    Mashpriborintorg
    Negretti & Zambra
    Ogawa Seiki
    Rigosha
    Società Italiana Apparecchi Precisione
    Tsurumi-Seiki Kosakusho
    Watanabe Keiki Manufacturing
    Wildlife Supply
    Yoshino Keiki

1. THERMOPROBE, SEA FLOOR (see 82.v)

2. TIDE RECORDERS, WATER LEVEL GAUGES, LIMNIGRAPHS
    Airtronics
    Bergen Nautik
    Braincon
    Bristol
    Fisher Research
    Foxboro
    Gaertner Scientific
    Gems
    Geodyne
    W. & L. E. Gurley
    Honeywell, Industrial Products
    Hydro Products
    Hytech
    Kahl Scientific Instrument
    Leupold & Stevens
    Marine Advisers
    Mashpriborintorg
    Mécabolier
    National Marine Consultants
    Negretti & Zambra
    Neyrpic
    Ogawa Seiki
    A. Ott
    Rigosha
    Simonsen Radio
    Società Italiana Apparecchi Precisione
    "Thalassia" di Dario Pagan
    Tsurumi-Seiki Kosakusho
    Dr. H. Züllig, Apparatebau

113. TIMER, ELECTRICAL
    Airtronics
    Braincon
    Concord Control
    Electronic Specialty
    Geodyne
    Hamilton Watch
    Hydro Products
    National Marine Consultants
    Ocean Research Equipment
    Sea Space Systems
    Specialty Electronics Development

114. TIMER, SELF-CONTAINED
  a. *Battery powered*
    Airtronics
    Braincon
    Elcontrol
    Geodyne
    Geotechnical
    Hamilton Watch
    Hydro Products
    Marine Advisers
    National Marine Consultants
    Ocean Research Equipment
    Oceanic Instruments
    Sea Space Systems
    Specialty Electronics Development
  b. *Mechanical*
    Braincon
    General Biological Supply House
    Geodyne
    Hamilton Watch
    Hydro Products
    Ocean Research Equipment
    Sea Space Systems
    Specialty Electronics Development
    Ward's Natural Science Establishment

115. TOWED INSTRUMENT BODIES OR VEHICLES (see also 19)
  a. *Automatic or remote control*
    Clevite Ordnance
    Commercial Engineering
    Hydro Products
  b. *Passive*
    Goodyear Aircraft
    KPT Manufacturing
    Loral Electronics
    Ocean Research Equipment

116. TOWED INSTRUMENT SYSTEMS (VEHICLE, FAIRED CHAIN OR CABLE, AND HOIST)
    Commercial Engineering

117. TRANSDUCERS, ACOUSTIC (see 126.h)

118. TRANSDUCERS, GENERAL (see 91)

119. TRAWL, MID-WATER
    Alpine Geophysical
    Bendix, Bendix-Pacific Div.
    Consolidated Net & Twine
    Dominion Textile
    Fish Net & Twine
    Hytech

119. Trawl, mid-water (contd.)
    - Marinovich Trawl
    - C. M. Murray Instrument
    - Puget Sound Workshop
    - Triton Marine Products
120. TRITIUM ANALYSIS EQUIPMENT
    - Hydro Products
    - Nuclear Chicago
    - Tracerlab
121. TRITIUM LABELED CHEMICALS
    - New England Nuclear
122. TRITIUM SAMPLING APPARATUS
    - Kurt Gohla
    - Oceanic Instruments
123. TRIPPING AND RELEASING DEVICES
    - a. *Hydrostatic*
        - Kahl Scientific Instrument
    - b. *Mechanical, by messenger*
        - Braincon
        - Hans Büchi
        - General Engineering & Scientific
        - Geodyne
        - Hydro Products
        - Hytech
        - Kahl Scientific Instrument
        - Marine Advisers
        - Mécabolier
        - C. M. Murray Instrument
        - Ocean Research Equipment
        - Puget Sound Workshop
        - Rigosha
        - Fred Schueler
        - "Thalassia" di Dario Pagan
        - Wildlife Supply
    - c. *Power pulse source, sequenced by sonic signal*
        - Ramsay Engineering
124. TURBIDITY METER (see 50.a, 50.c, 50.d)
125. TWINES, SPECIALTY SYNTHETIC
    - Brownell
    - Fish Net & Twine

U

126. UNDERWATER ACOUSTIC EQUIPMENT AND INSTRUMENTS
    - a. *Acoustic fish tags* (see 102.a)
    - b. *Acoustic flowmeter* (see 28.a)
    - c. *Acoustic markers, subsurface, self-contained* (see also 14.c)
        - Clevite Ordnance
        - Hydro Products
    - d. *Ambient noise measuring system*
        - ACF Industries
        - Aerojet-General
        - Geraldines Laboratories
    - e. *Bottom detectors and indicators* (see 12)
    - f. *Communication and telemetry systems*
        - Bendix, Bendix-Pacific Div.
        - Clevite Ordnance
        - Di-Conex
        - Straza Industries
    - g. *Echo sounders* (see 82.f)
    - h. *Hydrophones and preamplifiers*
        - ACF Industries
        - Aerojet-General
        - American Submarine
        - Astropower
        - Bendix, Bendix-Pacific Div.
        - S. G. Brown
        - Chesapeake Instrument
        - Clevite Ordnance
        - Cohu Electronics, Massa Div.
        - Daystrom
        - Di-Conex
        - Dyna-Empire
        - Edgerton, Germeshausen & Grier
        - Edo
        - General Dynamics/Electronics
        - General Electric, HMED
        - General Instrument, Harris ASW Div.
        - Geraldines Laboratories
        - Giannini Controls
        - Gulton Industries, Marine Instrument Dept.
        - Honeywell, Seattle Development Laboratory
        - HRB-Singer
        - Hydro Products
        - Instrument Systems, Telephonics Div.
        - Mandrel Industries, Electro-Tech Labs. Div.
        - Marsh & Marine
        - Martin, Electronic S & P Div.
        - Polarad Electronics
        - RADCOM
        - Rayflex Exploration
        - Raytheon
        - Research Manufacturing
        - Rigosha
        - Simonsen Radio
        - United Research
        - Westinghouse Defense Products
    - i. *Precision depth recorder* (see 82.l)
    - j. *Sonar, diver-held* (see also 126.l)
        - Burnett Electronics
        - Cohu Electronics, Massa Div.
        - Dalmo Victor
        - Geraldines Laboratories
        - Hydro Products
    - k. *Sonar, fish-locating*
        - Alpine Geophysical
        - American Submarine
        - Bendix, Bendix-Pacific Div.
        - Cohu Electronics, Massa Div.
        - Di-Conex
        - Dyna-Empire
        - Edo
        - Electroacustic
        - General Electric, HMED
        - Geraldines Laboratories
        - Honeywell, Seattle Development Laboratory
        - Instrument Systems, Telephonics Div.
        - Oceanic Instruments
        - RADCOM

6. Underwater acoustic equipt., instr. (contd.)
    - Ross Laboratories
    - Simonsen Radio
    - Straza Industries
    - Triton Marine Products
- l. *Sonar, short range, high resolution* (see also 126.j)
    - Clevite Ordnance
    - Daystrom
- m. *Sound velocity recorders* (see 82.o) *or sensors* (see 91.n)
- n. *Swallow float (neutral buoyancy acoustic pinger)*
    - Alpine Geophysical
    - Edgerton, Germeshausen & Grier
    - Gulton Industries, Marine Instrument Dept.
    - Hydro Products
    - Hytech
    - Ocean Research Equipment
    - Research Manufacturing

V

7. Vehicles, manned (see 100)

8. Vehicles, unmanned, for instruments
- a. *Crawler* (see 62)
- b. *Towed* (see 115)

9. Vessels, charter or lease (see 92.f)

0. Vibratron pressure transducer (see 91.r)

W

1. *Water analysis equipment, limnological*
    - Beckman Instruments
    - Kurt Gohla
    - W. & L. E. Gurley
    - Hellige
    - Hydro-Bios Apparatebau
    - La Motte Chemical Products
    - Membranfiltergesellschaft
    - Ogawa Seiki
    - Rigosha
    - W. A. Taylor
    - Tsurumi-Seiki Kosakusho
    - Wildlife Supply

2. Water level gauges or recorders (see 112)

3. Water sampling bottles and devices
- a. *Automatic multiple sampler (battery operated)*
    - Elcontrol Ltd.
- b. *Bottom water sampler*
    - Hydro-Bios Apparatebau
    - Rigosha
    - Tsurumi-Seiki Kosakusho
    - Dr. H. Züllig, Apparatebau
- c. *Collapsible neoprene*
    - Bolt Associates
- d. *Continuous sampler (time integrated)*
    - Curtiss–Wright, Electronics Div.
    - Mashpriborintorg
- e. *Ekman*
    - Elliott & Garrood
    - Kahl Scientific Instrument
    - Kurt Gohla
    - Rigosha
    - S. Smith & Sons (England)
    - "Thalassia" di Dario Pagan
    - Tsurumi-Seiki Kosakusho
    - Watanabe Keiki Manufacturing
- f. *Fjarlie*
    - Hydro-Bios Apparatebau
    - Hydro Products
    - Kahl Scientific Instrument
- g. *Frautschy*
    - Hytech
    - Kahl Scientific Instrument
- h. *Friedinger*
    - Hans Büchi
- i. *Horizontal*
    - Rigosha
- j. *Kemmerer*
    - Hydro-Bios Apparatebau
    - Wildlife Supply
- k. *Knudsen reversing, frameless*
    - Laboratoire Océanographique
- l. *Krummel–Pettersson–Schweder*
    - Kurt Gohla
    - Hydro-Bios Apparatebau
    - S. Smith & Sons (England)
- m. *Nansen*
    - Bergen Nautik
    - General Engineering & Scientific
    - Kurt Gohla
    - Hydro-Bios Apparatebau
    - Hydrowerkstätten
    - Kahl Scientific Instrument
    - Mécabolier
    - C. M. Murray Instrument
    - Rigosha
    - Fred Schueler
    - "Thalassia" di Dario Pagan
    - Tsurumi-Seiki Kosakusho
    - Watanabe Keiki Manufacturing
- n. *Non-metallic*
    - Bergen Nautik
    - Hydro Products
    - Hydro-Bios Apparatebau
    - Hytech
    - Kahl Scientific Instrument
    - C. M. Murray Instrument
    - Oceanic Instruments
    - Ogawa Seiki
    - Rigosha
    - Fred Schueler
    - Logan Smith & Associates
    - "Thalassia" di Dario Pagan
    - Tsurumi-Seiki Kosakusho
    - Watanabe Keiki Manufacturing
- o. *Pettersson–Nansen (insulated)*
    - Bergen Nautik
    - Elliott & Garrood
    - Kurt Gohla
    - Hydro-Bios Apparatebau

133. Water sampling bottles, devices (contd.)
    - Hydrowerkstätten
    - International Agency for Carbon-14 Determination
    - Laboratoire Océanographique
    - Rigosha
    - S. Smith & Sons (England)
    - Watanabe Keiki Manufacturing
  - p. *Ruttner*
    - "Thalassia" di Dario Pagan
  - q. *Sea sampler, multiple (Spilhaus-Miller, Koto, or other)*
    - S. G. Brown
    - Hydro-Bios Apparatebau
    - Mashpriborintorg
    - Rigosha
  - r. *Sterile (bacterial) general*
    - A. Gallenkamp
    - Hydro Products
    - Hytech
    - Kahl Scientific Instrument
    - Membranfiltergesellschaft
    - Plankton Research Instruments
    - Rigosha
    - "Thalassia" di Dario Pagan
  - s. *Sterile, Cobet*
    - Hydro Products
  - t. *Sterile, ZoBell*
    - Kahl Scientific Instrument
  - u. *Theiler*
    - Dr. H. Züllig, Apparatebau
  - v. *Wohlenberg–Schweder*
    - Kurt Gohla
    - Hydro-Bios Apparatebau
    - Mécabolier
  - w. *50-gallon collapsible rubber water sampler*
    - Goodyear Aircraft
    - U. S. Rubber
  - x. *Other*
    - C. F. Casella
    - Elcontrol
    - Elliott & Garrood
    - General Dynamics/Electronics
    - Gulton Industries, Marine Instrument Dept.
    - Ogawa Seiki
    - Rigosha
    - Tsurumi-Seiki Kosakusho

134. WAVE RECORDERS, SEA AND SWELL
  - a. *Airborne*
    - Astropower
    - Century Electronics & Instruments
    - Northrop Nortronics
    - RADCOM
    - Sea Space Systems
  - b. *Open sea*
    - Mashpriborintorg
  - c. *Pressure*
    - Airtronics
    - Alpine Geophysical
    - Astropower
    - Braincon
    - Century Electronics & Instruments
    - Colvin Laboratories
    - Hydro Products
    - Hytech
    - Marine Advisers
    - Pratt & Whitney
    - Rigosha
    - Sea Space Systems
    - Tsurumi-Seiki Kosakusho
  - d. *Seabed acoustic*
    - S. Smith & Sons (England)
  - e. *Surface contact*
    - Airtronics
    - Astropower
    - Gems
    - General Electric, HMED
    - Geodyne
    - Honeywell, Seattle Development Laboratory
    - Hydro Products
    - National Marine Consultants
    - Sea Space Systems
    - Simonsen Radio

135. WAVE RECORDERS, TIDE (see 112)

136. WAVE RECORDERS, TSUNAMI (LONG PERIOD)
    - Alpine Geophysical
    - Bendix, Bendix-Pacific Div.
    - Hydro Products
    - Marine Advisers
    - Sea Space Systems
    - Tsurumi-Seiki Kosakusho

137. WINCHES
  - a. *Bathythermograph* (see also 137.f)
    - Acco Equipment Division
    - Alpine Geophysical
    - Commercial Engineering
    - Fletcher Aviation
    - Hydro Products
    - Hydro-Bios Apparatebau
    - Hytech
    - Kahl Scientific Instrument
    - Marine Construction & Design
    - Markey Machinery
    - Mécabolier
    - New England Trawler Equipment
    - Rigosha
    - S. Smith & Sons (England)
    - Submarine Cables
    - Tsurumi-Seiki Kosakusho
  - b. *Constant tension*
    - Clevite Ordnance
  - c. *Dredging and trawl*
    - Alpine Geophysical
    - Baldwin–Lima–Hamilton, Industrial Equipment Div.
    - Commercial Engineering
    - Construction Aggregates
    - Elliott & Garrood
    - Fletcher Aviation
    - Marine Construction & Design
    - Marine Machine Works
    - Marinovich Trawl
    - Markey Machinery

7. Winches (contd.)
    - New England Trawler Equipment
    - Pratt & Whitney
    - Stroudsburg Engine Works
    - Submarine Cables
    - Tsurumi-Seiki Kosakusho
    - Vickers
    - Western Gear
  - d. *Electric cable*
    - Commercial Engineering
    - Elliott & Garrood
  - e. *Hand*
    - Astropower
    - Beak & Egger
    - Bergen Nautik
    - Hans Büchi
    - Commercial Engineering
    - Elliott & Garrood
    - Kurt Gohla
    - Hydro-Bios Apparatebau
    - Hydrowerkstätten
    - Kahl Scientific Instrument
    - Laboratoire Océanographique
    - Marine Exploration
    - Marinovich Trawl
    - Markey Machinery
    - Mashpriborintorg
    - Mécabolier
    - C. M. Murray Instrument
    - New England Trawler Equipment
    - Ocean Research Equipment
    - A. Ott
    - Rigosha
    - "Thalassia" di Dario Pagan
    - Tsurumi-Seiki Kosakusho
    - Vickers
    - Wildlife Supply
  - f. *Limnological, light duty (powered)* (see also 137.a)
    - Baldwin–Lima–Hamilton, Industrial Equipment Div.
    - Beak & Egger
    - Commercial Engineering
    - Marine Construction & Design
    - Marine Machine Works
    - New England Trawler Equipment
    - Rigosha
    - Stroudsburg Engine Works
    - Tsurumi-Seiki Kosakusho
    - Vickers
  - g. *Oceanographic*
    - Alpine Geophysical
    - Astropower
    - Baldwin–Lima–Hamilton, Industrial Equipment Div.
    - Bergen Nautik
    - Clevite Ordnance
    - Commercial Engineering
    - Electro-Mechanical Research
    - Elliott & Garrood
    - Fletcher Aviation
    - General Dynamics/Electronics
    - Hydro-Bios Apparatebau
    - Hytech
    - Instrument Systems, Telephonics Div.
    - KPT Manufacturing
    - Kahl Scientific Instrument
    - Laboratoire Océanographique
    - Ledeen Manufacturing
    - Marine Construction & Design
    - Marine Machine Works
    - Markey Machinery
    - Mécabolier
    - New England Trawler Equipment
    - PneumoDynamics
    - Pratt & Whitney
    - RADCOM
    - Rigosha
    - Sea Space Systems
    - Stroudsburg Engine Works
    - Submarine Cables
    - "Thalassia" di Dario Pagan
    - Tsurumi-Seiki Kosakusho
    - Vickers
    - Western Gear
  - h. *Sounding machines*
    - Bergen Nautik
    - Fletcher Aviation
    - Leupold & Stevens
    - Ogawa Seiki
    - Rigosha
    - S. Smith & Sons (England)
    - Submarine Cables
    - Tsurumi-Seiki Kosakusho

LIST OF FIRMS

A

Paul O. Abbe, Inc.,
P.O. Box 207, Little Falls, New Jersey 07424.

Acco Equipment Division,
American Chain & Cable Co., Inc., 1110 East Princess St., York, Pennsylvania 17403.

ACF Industries, Inc.,
ACF Electronics Division, 11 Park Place, Paramus, New Jersey 07653.

Aerojet-General Corp.,
Oceanics Division, P.O. Box 296, Azusa, California 91703.

Airtronics, Inc.,
5221 River Road, Washington, D. C. 20016.

Alfa American Corp.,
303 West 42nd Street, New York, New York 10036.

Aloe Scientific,
1831 Olive, St. Louis, Missouri 63103.

Alpine Geophysical Associates, Inc.,
55 Oak St., Norwood, New Jersey 07648.

American Diving Equipment Co.,
5600 West North Ave., Milwaukee, Wisconsin 53208.

American Submarine Co.,
400 Colorado Ave., Lorain, Ohio 44052.

Ampex Corp.,
934 Charter St., Redwood City, California 94063.

Anritsu Electronic Works, Ltd.,
Tokyo, Japan.

Ansonia Wire & Cable Co.,
111 Martin St., Ashton, Rhode Island 02805.

Applied Research Associates of Texas, Inc.,
6541 North Lamar Blvd., Austin, Texas 78752.

Askania-Werke
Continental Elektroindustrie, Grossbeerenstrasse 2–10, 1 Berlin (West) 42, Germany.
U.S. Branch Office:
4913 Cordell Ave., Bethesda, Maryland 20014.

Astropower, Inc.,
(see Douglas Aircraft Co., Inc.)

Atlantic Research Corp.,
Shirley Highway & Edsall Road, Alexandria, Virginia 22314.

Autonetics,
Inertial Navigation Division, 1230 North Miller St., Anaheim, California 92801.

B

Baird & Tatlock (London) Ltd.,
Freshwater Road, Chadwell Heath, Essex, England.

Baldwin–Lima–Hamilton Corp.,
Electronics Division, 42 Fourth Avenue, Waltham, Massachusetts 02154.
Industrial Equipment Division (formerly C. H. Wheeler Mfg. Co.), Philadelphia, Pennsylvania 19142.

Barber–Colman Co.,
1300 Rock St., Rockford, Illinois 61111.

Barnes Engineering Co.,
44 Commerce Road, Stamford, Connecticut 06902.

Beak & Egger,
Box 220, Collins Bay, Ontario, Canada.

Beckman Instruments, Inc.,
2500 Harbor Blvd., Fullerton, California 92632.

Beckman & Whitley, Inc.,
993 San Carlos Ave., San Carlos, California 94071.

Belfort Instrument Co.,
4 North Central Ave., Baltimore, Maryland 21202.

The Bendix Corp.,
Bendix-Pacific Division, 11600 Sherman Way, North Hollywood, California 91605.
Friez Instrument Division, 1400 Taylor Ave., Towson, Maryland 21234.

Benson–Lehner Corp.,
14761 Califa St., Van Nuys, California 91401

Benthos Co.,
Old Main Road, North Falmouth, Massachusetts 02556.

Bergen Nautik A/S,
Strandgaten 18, Bergen, Norway.

Bludworth Marine Co.,
92 Gold St., New York, New York 10038.

Bolt Associates,
78 Danbury Road, Wilton, Connecticut 06897.

Borg–Warner Controls,
3300 Newport Blvd., Santa Ana, California 92705.

Boston Insulated Wire & Cable Co.,
26 Bay St., Boston, Massachusetts 02125.

The Botany School,
Culture Collection of Algae & Protozoa, Downing St., Cambridge, England.

Braincon Corp.,
P.O. Box 267, Marion, Massachusetts 02738.

Brinkman Instruments Inc.,
115 Cutter Mill Road, Great Neck, L. I. New York 11021.

The Bristol Co.,
Bristol Road, Waterbury, Connecticut 06720.

Burleigh Brooks, Inc., 10 West 46th Street,
New York, New York 10036.

S. G. Brown, Ltd.,
Shakespeare St., Watford, Hertford, England.

Brownell & Co., Inc.,
Moodus, Connecticut 06469.

Hans Büchi, Hydrobiological Equipment,
Spitalgasse 18/Marktgasse 53., Bern, Switzerland.

Dr. R. Burkard,
Kantons Chemiker, Solothurn, Switzerland.

Burnett Electronics Laboratory, Inc.,
P.O. Box 20005, San Diego, California 92120.

C

lifornia Eastern Engineering,
9322 La Jolla Farms Road, La Jolla, California 92037.
nest Case,
R.F.D., Andover, New Jersey 07821.
F. Casella & Co., Ltd.,
Regent House, Britannia Walk, London N. 1, England.
stle Industries, Inc.,
P.O. Box 859, Everett, Washington 98202.
ntre de Recherches Hydrobiologiques du C.N.R.S.,
Gif-sur-Yvette, S et O, France.
ntury Engineers, Inc.,
2741 North Naomi St., Burbank, California 91504.
ntury Electronics & Instruments, Inc.,
6540 East Apache, Tulsa, Oklahoma 74115.
emical Insecticide Corp.,
30 Whitman Ave., Metuchen, New Jersey 08841.
esapeake Instrument Corp.,
Shadyside, Maryland 20867.
evite Ordnance,
Div. of Clevite Corp., 540 East 105th Street, Cleveland, Ohio 44108.
I^2,
529 East Evelyn St., Mountain View, California 94041.
hu Electronics, Inc.,
Kin Tel Division, 5725 Kearny Villa Road, San Diego, California 92123.
Massa Division, 280 Lincoln St., Hingham, Massachusetts 02043.
lvin Laboratories, Inc.,
364 Glenwood Ave., East Orange, New Jersey 07017.
mmercial Engineering Corp.,
5205 Ashbrook, Houston, Texas 77036.
mpagnie Générale de Metrologie-Metrix,
Chemin de la Croix-Rouge, Annecy, Haute Savoie, France.
ncord Control, Inc.,
1282 Soldiers Field Road, Boston, Massachusetts 02135.
nsolidated Electrodynamics Corp.,
Subsidiary of Bell & Howell Co.,
360 Sierra Madre Villa, Pasadena, California 91107.
nsolidated Net & Twine Co., Inc.,
Fishermen's Terminal, Seattle, Washington 98199.
nsolidated Systems Corp.,
1500 South Shamrock Ave., Monrovia, California 91016.
nstruction Aggregates Corp.,
120 South LaSalle St., Chicago, Illinois 60603.
ulter Electronics Industrial Division,
2525 North Sheffield Ave., Chicago, Illinois 60657.
Craftsweld Equipment Corp.,
26–26 Jackson Ave., Long Island City, New York 11101.
Robert M. Crosby,
45 Thornhill Road, Lutherville, Maryland 21093.
Curtiss–Wright Corp.,
Electronics Division, Measurement and Control Products, 35 Market St., East Paterson, New Jersey 07407.

D

Dacor Corp.,
P.O. Box 551, Evanston, Illinois 60204.
Dale Plastics Corp.,
5736 Twelfth Street, Detroit, Michigan 48208.
Dalmo Victor Co.,
1515 Industrial Way, Belmont, California 94002.
Danforth/White,
Div. of The Eastern Co., 180 Anderson St., Portland, Maine 04101.
Dart Aircraft, Ltd.,
Market Place, Chalfont St., Peter, Bucks., England.
Daystrom, Inc.,
Electric Division, 229 Manchester Road, Poughkeepsie, New York 12603.
Decca Navigator, Ltd.,
Decca House, Albert Embankment, London, S.E. 1, England.
U.S. Office:
Decca Navigator, Inc., 11th Floor, 386 Park Avenue South, New York, New York 10016.
Di-Conex Corp.,
P.O. Box 1331, Pascagoula, Mississippi 39567.
W. C. Dillon & Co., Inc.,
14620 Keswick St., Van Nuys, California 91405.
Dittmore–Freimuth Corp.,
2517 East Norwich St., Milwaukee, Wisconsin 53207.
Diving Corporation of America,
722 S. W. 8th Street, Miami, Florida 33136.
Diving Equipment & Supply Co.,
212 North Broadway, Milwaukee, Wisconsin 53202.
Dominion Textile Co., Ltd.,
Drummondville Division, P.O. Box 6250, Montreal, Canada.
Dotsom–Kimes Enterprises,
4339 Corinth Ave., Culver City, California 90230.
Douglas Aircraft Co., Inc.,
Advanced Technology, Cl-250,
3855 Lakewood Blvd., Long Beach, California 90801.
Dyna-Empire, Inc.,
1075 Stewart Ave., Garden City, New York 11533.

E

Edgerton, Germeshausen & Grier, Inc.,
160 Brookline Ave., Boston, Massachusetts 02215.

Edo Corp.,
13–10 111th Street, College Point, L. I., New York 11356.

Elcontrol Ltd.,
42 Wilbury Way, Hitchin, Herts., England.

Electroacustic G.m.b.H,
Westring 425/429, Kiel, Germany.

Electro-Mechanical Research, Inc.,
P.O. Box 3041, Sarasota, Florida 33578.

Electronic Specialty Co.,
5121 San Fernando Road, Los Angeles, California 90039.

Electro-Oceanics,
1249 Melba Road, Encinitas, California 92024.

Elin-Union,
Volksgartenstrasse 3, Wien I, Austria.

Elliott & Garrood Ltd.,
Beccles, Suffolk, England.

The Eppley Laboratory, Inc.,
12 Sheffield Ave., Newport, Rhode Island 02842.

F

R. L. Faley & Associates, Inc.,
5716 Southwest Freeway, Houston, Texas 77027.

Farrand Optical Co., Inc.,
Bronx Blvd. & East 238th Street, New York, New York 10470.

Feldmann Engineering & Mfg. Co.,
633–639 Monroe St., Sheboygan Falls, Wisconsin 53085.

Fenjohn Underwater Photo & Equipment Co.,
90 Cricket Ave., Ardmore, Pennsylvania 19003.

Fenwal Electronics, Inc.,
63 Fountain St., Framingham, Massachusetts 01701.

The Fish Net & Twine Co.,
927 First Street, Menominee, Michigan 49858.

Fisher Research Laboratory, Inc.,
1975 University Ave., Palo Alto, California 94302.

Flatters & Garnett Ltd.,
309 Oxford Road, Manchester 13, England.

Fletcher Aviation Co.,
9400 Flair Road, El Monte, California 91731.

Flow Corp.,
205 Sixth Street, Cambridge, Massachusetts 02142.

The Foxboro Co.,
Foxboro, Massachusetts 02035.

Freshwater Biological Association,
The Ferry House, Far Sawrey, Ambleside, Westmorland, England.

G

The Gaertner Scientific Corp.,
1201 Wrightwood Ave., Chicago, Illinois 60614.

Roberto Galeazzi S.A.S.,
Via Oldoini 75, La Spezia, Italy.

A. Gallenkamp & Co., Ltd.,
Technico House, Christopher St., London E.C. 2, England.

The Garrett Corp.,
(Northill Airmite), Belmar, New Jersey 07719.

Gelman Instrument Co.,
600 South Wagner Road, Ann Arbor, Michigan 48106.

The Gems Co., Inc.,
P.O. Box 255, Spring Lane, Farmington, Connecticut 06023.

General Biological Supply House, Inc.,
8200 South Hayne Ave., Chicago, Illinois 60620.

General Dynamics/Electric Boat,
Groton, Connecticut.

General Dynamics/Electronics,
1400 North Goodman St., Rochester, New York 14609.

General Electric Co.,
Heavy Military Electronics Dept., Marine and Underseas Programs, Building 3, Court St., Syracuse, New York 13208.

The General Engineering & Scientific Co.,
Waltair, Visakhapatnam-3, India.

General Instrument Corp.,
Harris ASW Division, 33 Southwest Park, Westwood, Massachusetts 02091.

General Motors Corp.,
Defense Research Laboratories, Box T, Santa Barbara, California 93102.

General Precision, Inc.,
Kearfott Division, 1500 Main Ave., Clifton, New Jersey 07011.

General Scientific Corp.,
5223 River Road, Washington, D. C. 20016.

Geodyne Corp.,
151 Bear Hill Road, Waltham, Massachusetts 02154.

The Geotechnical Corp.,
3401 Shiloh Road, Garland, Texas 75041.

The Geraldines Laboratories,
Div. of Bell Aerospace Corp., 90 Compromise St., Annapolis, Maryland 21401.

The Gerber Scientific Instrument Co.,
P.O. Box 305, Hartford, Connecticut 06101.

Giannini Controls Corp.,
1600 South Mountain Ave., Duarte, California 91010.

Glotex Importers Co.,
15 East 26th Street, New York, New York 10010.

Kurt Gohla,
Lornsenstrasse 43, 23 Kiel, Germany.

Goodyear Aircraft Corp.,
1210 Masillon Road, Akron, Ohio 44306.

Great Western Mfg. Co.,
208 Choctaw St., Leavenworth, Kansas 66048.

Gulton Industries, Inc.,
Marine Instrument Dept., 605 N. E. 33rd Street, Pompano Beach, Florida 33064.

W. & L. E. Gurley,
514 Fulton St., Troy, New York 12180.

H

Hamilton Watch Co.,
Columbia Ave., Lancaster, Pennsylvania 17603.

Hastings–Raydist, Inc.,
Newcomb Ave., Hampton, Virginia 23369.

The Hays Corp.,
750 East 8th Street, Michigan City, Indiana 46361.

Healthways of Los Angeles,
3669—7th Avenue, Los Angeles, California 90018.

Hellige, Inc.,
877 Stewart Ave., Garden City, New York 11533.

Hewlett–Packard Co.,
1501 Page Mill Road, Palo Alto, California 94303.

Hinde Engineering Co.,
224 Linden Park Place, Highland Park, Illinois 60035.

Hoffman Electronics Corp.,
Science Center Division, P.O. Drawer H, Santa Barbara, California 93102.

Honeywell,
Industrial Products Group, Wayne & Windrim Avenues, Philadelphia, Pennsylvania 19144.
Seattle Development Laboratory, 5303 Shilshole Avenue, N. W., Seattle, Washington 98107.

HRB-Singer, Inc.,
P.O. Box 60, Science Park, State College, Pennsylvania 16801.

Hydro Products Co.,
Div. of Oceanographic Engineering Corp., 4930 Naples Place, San Diego, California 92110.

Hydro-Bios Apparatebau G.m.b.H.,
Wismarerstrasse 14., 23 Kiel, Germany.

Hydro-Space Technology, Inc.,
Clinton Road and Route 46, West Caldwell, New Jersey 17007.

Hydrowerkstätten,
Uhlenkrog 38, Kiel-Hassee, Germany.

Hytech,
Division of Bissett–Berman Corp., "G" Street Pier, San Diego, California 92101.

I

Imperial Thermal Systems, Inc.,
6450 Dale St., Buena Park, California 90621.

Industrial Instruments Inc.,
89 Commerce Road, Cedar Grove, New Jersey 07009.

Instituto de Investigaciones Pesqueras,
Laboratorio de Cadiz, España.

Instrument Mfg. Corp. of South Africa, Ltd.,
P.O. Box 23, Plumstead, C.P., South Africa.

Instrument Systems Corp.,
Telephonics Division, Park Ave., Huntington, L.I., New York 11743.

International Agency for Carbon-14 Determination,
Charlottenlund Slot, Charlottenlund, Denmark.

International Underwater Research Corp.,
P.O. Box 1203, Providence, Rhode Island 02901.

ITT Federal Laboratories,
500 Washington Ave., Nutley, New Jersey 07110.

J

Jarrell–Ash Co.,
26 Farwell St., Newtonville, Massachusetts 02160.

The C. O. Jelliff Mfg. Corp.,
Pequot Road, Southport, Connecticut 06490.

Joy Manufacturing Co.,
Electrical Products Dept., 338 South Broadway, New Philadelphia, Ohio 44663.

K

Kahl Scientific Instrument Corp.,
P.O. Box 1166, El Cajon, California 92022.

Ketchum Manufacturing Sales, Ltd.,
396 Berkley Ave., Ottawa, Canada.

Kieler Howaldtswerke A.G.,
Abt. Apparatebau (24b), Kiel-N.-D., Germany.

P. J. Kipp & Zonen,
Delft, Netherlands.

KPT Manufacturing Co.,
Locust Ave., Roseland, New Jersey 07068.

Kressilk Products, Inc.,
73 Murray St., New York, New York 10007.

L

Laboratoire de Cryptogamie du Muséum,
12, Rue de Buffon, Paris (5^e), France.

Laboratoire Océanographique,
Postbox 19, Charlottenlund, Denmark.

Lacoste & Romberg,
6606 North Lamar Blvd., Austin, Texas 78752.

La Motte Chemical Products Co.,
Chestertown, Maryland 21620.

Ledeen Manufacturing Co.,
3350 North Gilman Road, El Monte, California 91732.

Leeds & Northrup Co.,
4901 Stenton Ave., Philadelphia, Pennsylvania 19144.

Leupold & Stevens Instruments, Inc.,
4445 N. E. Glisan St., Portland, Oregon 97213.

Lithium Corporation of America, Inc.,
500 Fifth Avenue, New York, New York 10036.

Lockheed Electronics Co.,
Avionics & Industrial Products Div., 6201 East Randolph St., Los Angeles, California 90028.

Loral Electronics Corp.,
825 Bronx River Ave., New York, New York 10462.

M

M. & E. Marine Supply Co.,
P.O. Box 601, Camden, New Jersey 08101.

Macalaster Scientific Corp.,
243 Broadway at Windsor St., Cambridge, Massachusetts 02139.

Macleod Instrument Corp.,
4250 Northwest 10th Avenue, Fort Lauderdale, Florida 33309.

Mako Products,
Division of Underwater Sports, Inc., 2931 Northeast 2nd Avenue, Miami, Florida 33137.

Mandrel Industries, Inc.,
Electro-Technical Labs Division, 5234 Glenmont Drive, Houston, Texas 77036.

Marine Acoustical Services, Inc.,
1975 N. W. South River Drive, Miami, Florida 33125.

Marine Advisers, Inc.,
P.O. Box 1963, 7440 Girard Ave., La Jolla, California 92038.

Marine Construction & Design Co.,
2300 West Commodore Way, Seattle, Washington 98199.

Marine Exploration Co., Inc.,
561 West 35th Place, Hialeah, Florida 33012.

Marine Laboratories,
University of Miami, Miami, Florida 33124.

Marine Machine Works,
2021 Avenue B, Galveston, Texas 77550.

Marinovich Trawl Co.,
P.O. Box 294, Biloxi, Mississippi 39533.

The Mark Co.,
31 West Street, Randolph, Massachusetts 02368.

Markey Machinery Co., Inc.,
79 South Horton St., Seattle, Washington 98134.

Mar-Mac Industries,
1453 Revere Ave., Hayward, California 94544.

Marsh & Marine Mfg. Co., Inc.,
5123 Gulfton Drive, Houston, Texas 77036.

The Martin Co.,
Electronic Systems & Products Division, Middle River, Baltimore, Maryland 21220.

Mashpriborintorg,
Smolenskaja pl. 32/34, Moskva, G-200, U.S.S.R.

Mécabolier,
79, Rue de la Glacière, Paris XIII, France.

Membranfiltergesellschaft G.m.b.H.,
P.O. Box 142, Göttingen, Germany.
U.S. Agent:
Carl Schleicher & Schuell Co.,
Keene, New Hampshire 03431.

Morse Diving Equipment Co.,
51 Sleeper Street, Boston, Massachusetts 02210.

F. L. Moseley Co.,
409 North Fair Oaks Ave., Pasadena, California 91103.

C. M. Murray Instrument Co.,
7715 5th Avenue South, Seattle, Washington 98108.

N

National Band & Tag Co.,
721–725 York St., Newport, Kentucky 41071.

National Marine Consultants,
c/o Interstate Electronics Corp., 707 East Vermont Ave., Anaheim, California 92805.

National Steel & Shipbuilding Co.,
28th and Harbor Drive, San Diego, California 92112.

Negretti & Zambra, Ltd.,
122 Regent St., London W. 1, England.

New England Nuclear Corp.,
575 Albany St., Boston, Massachusetts 02118.

New England Trawler Equipment Co.,
291 Eastern Ave., Chelsea, Massachusetts 02150.

Newark Wire Cloth Co.,
351 Veron Ave., Newark, New Jersey 07104.

Neyrpic, Inc.,
375 Park Ave., New York, New York 10016.

Northridge Research, Inc.,
18222 Parthenia St., Northridge, California 91324.

Northrop Nortronics,
Marine Equipment Dept., 77 A Street, Needham Heights, Massachusetts 02194.

Nuclear Chicago,
333 East Howard Ave., Des Plaines, Illinois 60018.

O

Ocean Research Equipment, Inc.,
Falmouth, Massachusetts 02541.

Ocean Science & Engineering, Inc.,
Dupont Circle Bldg., Washington, D.C. 20036.

Oceanic Instruments (see CM^2)

Oceanographic Industries,
1710 Purdy Ave., Miami Beach, Florida 33139.

Ogawa Seiki Co., Ltd.,
No. 184, 2 Chome, Hyakunin-cho, Shinjuku-ku, Tokyo, Japan.

Olympic Instruments, Inc.,
Vashon, Washington 98070.

OPTOMECHANISMS INC.,
Engineers Hill, Plainview, L.I. New York 11803.

A. OTT,
Mozartstrasse 18–20, 8960 Kempten/Allgäu, Germany.

P

S. B. PENICK & CO.,
4161 Beck Ave., St. Louis, Missouri 63116.

PERRY SUBMARINE BUILDERS, INC.,
2751 South Dixie Highway, West Palm Beach, Florida 33402.

E. E. PETERSON CO.,
7055 Eastondale Ave., Long Beach, California 90805.

PHILADELPHIA THERMOMETER CO.,
4401 North 6th Street, Philadelphia, Pennsylvania 19140.

PIKES PEAK ELECTRONICS CO.,
P.O. Box 319, Littleton, Colorado 80121.

PLANKTON RESEARCH INSTRUMENTS,
Box 582, Woods Hole, Massachusetts 02543.

PNEUMO DYNAMICS CORP.,
Systems Engineering Division, 4936 Fairmont Ave., Bethesda, Maryland 20014.

POLARAD ELECTRONICS CORP.,
Radiometrics Division, 43–20 34th Street, Long Island City, New York 11101.

PRATT & WHITNEY CO., INC.,
Charter Oak Blvd., West Hartford, Connecticut 06110.

PRECISION INSTRUMENT CO.,
3170 Porter Drive, Palo Alto, California 94304.

PRODELIN, INC.,
313 Bergen Ave., Kearny, New Jersey 07032.

PUGET SOUND WORKSHOP,
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SUPPLEMENTAL SOURCE MATERIAL

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A two-part bibliography of literature on oceanographic instruments or equipment, prepared for and with support from the U.S. National Oceanographic Data Center.

The subject matter of Part I includes general works; aspects, such as weather ships and marine meteorology; water sampling, temperature, salinity and acoustical instruments; optical, radiation, photographic and telemetering devices; and supplementary material, such as proceedings of conferences and summary or review articles.

The subject matter of Part II includes instruments for measuring waves, sea level, tides, currents, depth, physical properties of the sea floor and gravity; sediment tracers and samplers; biological samplers; and underwater breathing apparatus.

Scherago, Earl J. (compiler). 1963. **Guide to Scientific Instruments.** Science, **142**: 697–834.

This latest edition of the annual Instrument Guide issue has been compiled using machine techniques. "It organizes information in a coded pattern that will permit changes and revisions without destroying the usefulness of information published in the preceding guide. . . . These techniques will permit the distribution, between issues of the guide, of current information in machine language (magnetic tape, punched cards) and possibly on microfilm."

UNESCO and FAO. 1963. **International Marine Science, 1**(3), (Nov., 1963) ff.

This quarterly newsletter is distributed free of charge by the Office of Oceanography, Unesco, Paris, France, and the Biology Branch, Fisheries Division of FAO, Rome, Italy.

The first in a series of reports on oceanographic equipment and manufacturers appears in Section g. Miscellaneous News Items of vol. 1, no. 3, November 1963. Approximate prices are shown for apparatus in U.S. dollars. "It is intended that when the series is complete an accumulated report will be issued as a separate publication based on a revised list of equipment and manufacturers as shown in this section."

U.S. Fish and Wildlife Service. 1959. **Partial List of Manufacturers of Fishing Gear and Accessories and Vessel Equipment.** Fishery Leaflet **195**, 27 p.

Partially outdated but still valuable as general guide to fishing gear and shipboard equipment.

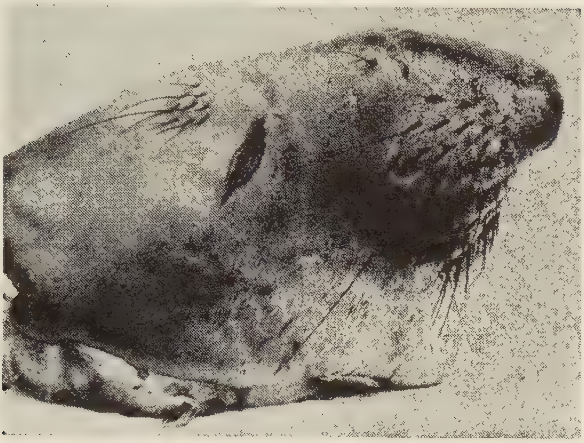
Thomas Register of American Manufacturers. 1963. 53rd ed. Thomas Publishing Co., New York, N.Y., 9,104 p. + supplement.

A comprehensive guide to established manufacturers and their products. Good source of information on industrial products in general use but deficient regarding specialized instruments for limnology and oceanography.

Undersea Technology. (monthly.) Sheffield Publishing Co., Washington D.C.

A magazine of oceanography, marine sciences, and underwater defense; distributed monthly on a controlled basis, without charge, to qualified persons working in the fields of undersea defense, antisubmarine warfare, oceanography, marine sciences, underseas exploration, and underwater construction, drilling, and mining. In addition to briefs, feature articles, and extensive advertising of marine equipment, UST provides an information service on pertinent products, (new) books, and descriptive literature. UST has published a series entitled "UST Glossary" compiled by Don Groves and Lee Hunt as follows: "General Terms," January 1963; "Underwater Sound," February and March 1963; "Sediment Sampling Devices," July 1963; and "Current Measuring Devices and Marine Biological Samplers," November 1963.

Deep Diving of Elephant Seals



Within a day or two of 26 August 1963, Thor Olsen and crew of the fishing boat ILENE, of Seattle, pulled a nylon set-line on which three seals were hooked by the mouth. Mr. Olsen told me about it on 16 September. The men were fishing for black cod *(Anoplopoma fimbria)* on the steeply sloping outer edge of Heceta Bank, 35 miles west of Florence, Oregon (lat. 44° N.), in about 100 fathoms of water. The line with baited hooks had been on the bottom for about 4 hours. The men spent 5 or 6 minutes in lifting the line. On one hook was a large dead seal, on another was an exhausted but live seal of similar size, and on a third hook was an exhausted seal distinctly the smallest. The seals were said to be "all of the same kind." The men released the two live ones and chopped off the head of the dead one as its heavy body lay awash beside the boat. They iced the head and brought it to Seattle.

The head is that of an elephant seal, *Mirounga angustirostris*, quite certainly a male, estimated age 2-3 years. The snout is neither as large nor as convoluted as an old male's. The pelage and teeth are unworn (above). Although several centimeters of the base of the skull (specimen BDM 578) are missing, the full condylobasal length would be about 32 cm. (An adult male skull in the National Museum [USNM 260867] has a CBL of 46.3 cm.). Many of the skull sutures are still open.

The crew saw no seals until they pulled the gear. I deduce that the two seals captured alive, and probably the dead one also, were hooked on the sea floor in about 100 fathoms of water shortly before the gear was pulled. It is inconceivable that the seals were hooked while the gear was being set and was in the process of sinking 4 hours earlier. There are no records of any pinniped having remained underwater for longer than about 25 minutes. — VICTOR B. SCHEFFER, *Marine Mammal Biological Laboratory, Bureau of Commercial Fisheries, U. S. Fish and Wildlife Service, Seattle, Washington.*

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p. 9

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ESTIMATING ABUNDANCE OF PELAGE FIBRES ON FUR SEAL SKIN

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[Accepted 9th April 1963]

(With 3 figures in the text)

Techniques are described for estimating the number of fibre groups, and the number of fibres per group, on a given area of skin of the northern fur seal, *Callorhinus ursinus* (L.).

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INTRODUCTION

On the surface of the skin of the fur seal each fibre group may be seen as an isolated bundle including one coarse guard hair (awn hair) and from nine to eighty-nine slender fur fibres (Scheffer, 1962). The number of fur fibres varies widely with age, sex, and season. Described below are methods (first) of collecting a known-area sample of skin, (second) of distinguishing fibre groups at magnifications of about × 20, and (third) of distinguishing individual fibres at magnifications of about × 200.

COLLECTING THE SAMPLE

On the mid-back or mid-belly of a freshly-killed seal, the four corners of a 10 cm square are marked by injecting a few drops of black waterproof ink from a 25 ml syringe through the pelage into the dermis. A block of skin-with-pelage, including the four ink marks, is removed by knife and pinned pelage-side down on a layer of wax in a dissecting tray. The block is stretched slightly in order to reorient the marks and to restore the skin to its living dimensions ; then it is fixed in 10 per cent formalin.

Several weeks later, or after the skin has hardened, a patch is sheared from the pelage (Fig. 1). An electric animal-clipper with thin surgical blade is pushed slowly against the lay of the wet fibres. After about ten runs over the same course, the residual stumps are either topped or are removed flush to the surface of the skin with a razor. It has been found that fibre groups can best be counted when the stumps protrude about 0·1 mm, while individual fibres can best be counted when the stumps are sectioned at, or slightly below, the surface.

From the sheared patch, five to ten circular discs of skin are cut with a trephine and lifted out with forceps. The trephine is a cylindrical steel tube sharpened at one end, 0·71 cm inside diameter, which cuts a disc 0·396 square cm in area (Carter & Clarke, 1957). At this operational stage, each disc contains approximately the same number of fibre groups that were originally present on 0·396 square cm of skin of the living seal. Subsequent treatment of the disc cannot change the number of groups, though it may distort the area of the disc.

Each disc is dehydrated in 98 per cent isopropanol, dried and flattened between filter papers under light pressure, and stored until needed.

DISTINGUISHING FIBRE GROUPS

About half of the discs in each sample, including those selected as having longer fibre stumps, are cleared for two days in cedarwood oil. Each is then placed on a microscope slide, pelage surface up, flooded with cedarwood oil, and covered with a glass slip. (Alpha-terpineol as a clearing medium has also been tried. It is equally effective but has two objectionable features : a pungent odour and a melting point of 25–32° C, slightly above usual room temperatures.) The disc is photographed at ×10 magnification with a lens of 32 mm focal length, by reflected light (Fig. 2). The fibre groups are counted by projecting the photo-negative to white paper and marking the image of each bundle with a spot of ink, while simultaneously pressing a hand-tally counter.

DISTINGUISHING INDIVIDUAL FIBRES

From one or more of the discs, including those selected as having shorter fibre stumps, thermoplastic impressions are made. Each disc is placed with its pelage surface against a strip of transparent cellulose acetate butyrate, " 010 gauge " (0·01 inch, or 0·25 mm, thick). The disc-with-strip is inserted in a screw compressor clamp such as chemists use for stopping the flow in rubber tubing, and the screw is tightened with the fingers. The clamp is heated on an electric hot plate for three minutes at 90° to 100° C. Then the strip is peeled away from the disc and examined under a microscope. At places where the surface texture of the disc has most clearly left an impression, a count is made of the individual fibres in 20 groups (Fig. 3).

This use of a thermoplastic medium is an extension of methods now in use for reproducing the surface texture of hair (Hardy & Plitt, 1940) and of fish scales (Lea & Went, 1936).

DISCUSSION

Fig. 2 represents a fibre group population of 939 per square cm. If it is assumed that this population is uniform over the entire haired surface of the body, then an average adult female seal with 52 fibres per group and a total

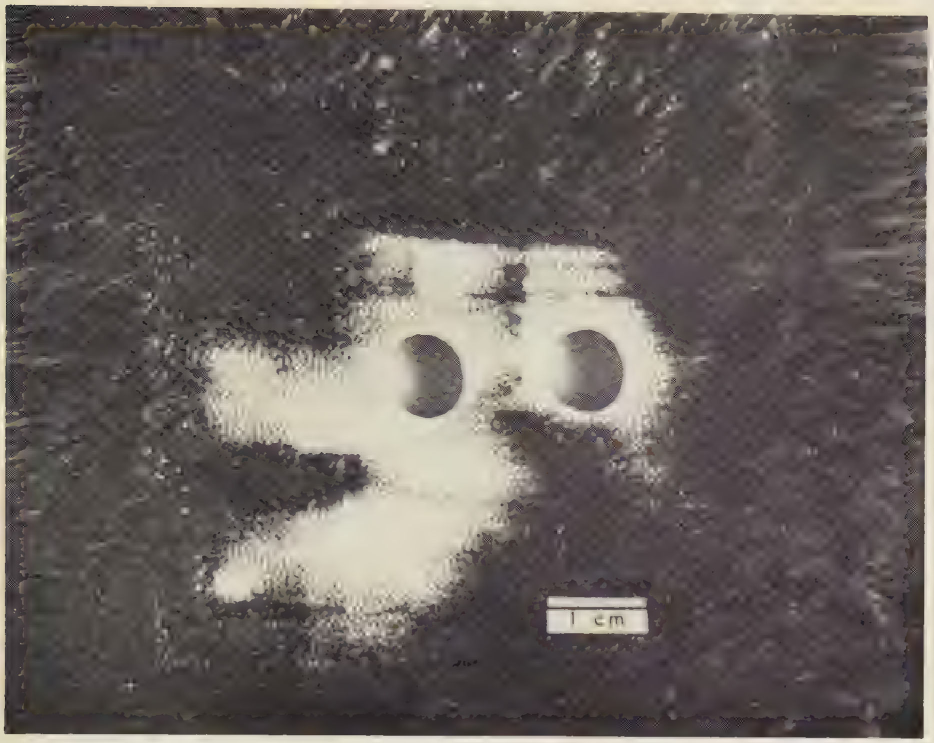

Fig. 1—Partly sheared surface of skin from the mid-belly of an adult female seal, with holes where two sample discs have been removed ; anterior end at left. (4942.)

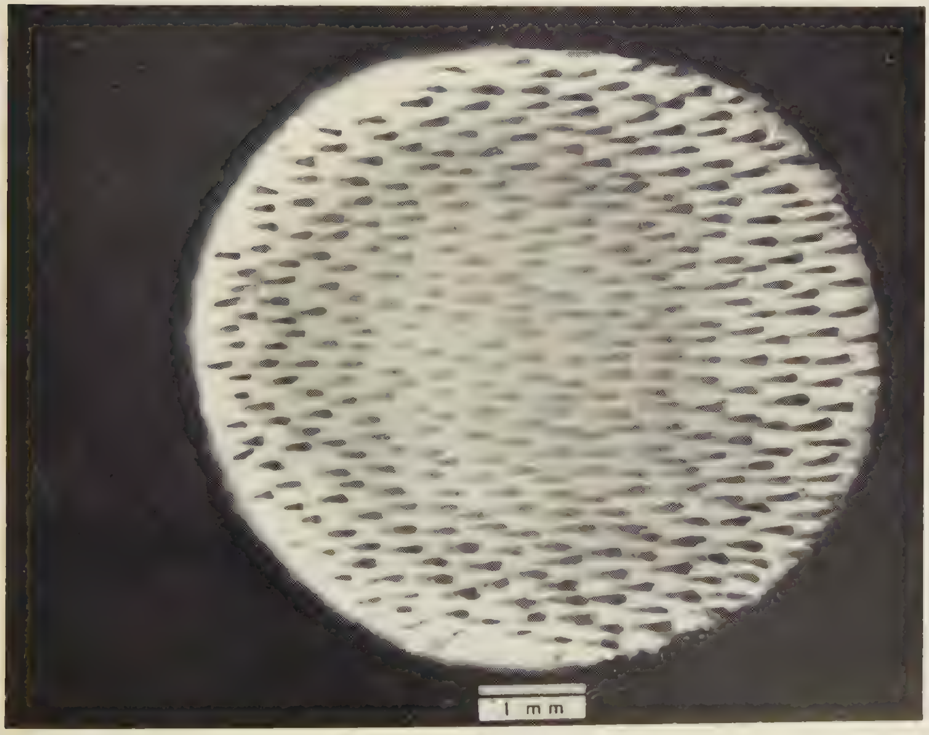

Fig. 2—Disc of skin (see above) cleared in cedarwood oil showing 372 fibre groups ; anterior end at left. (4934.)

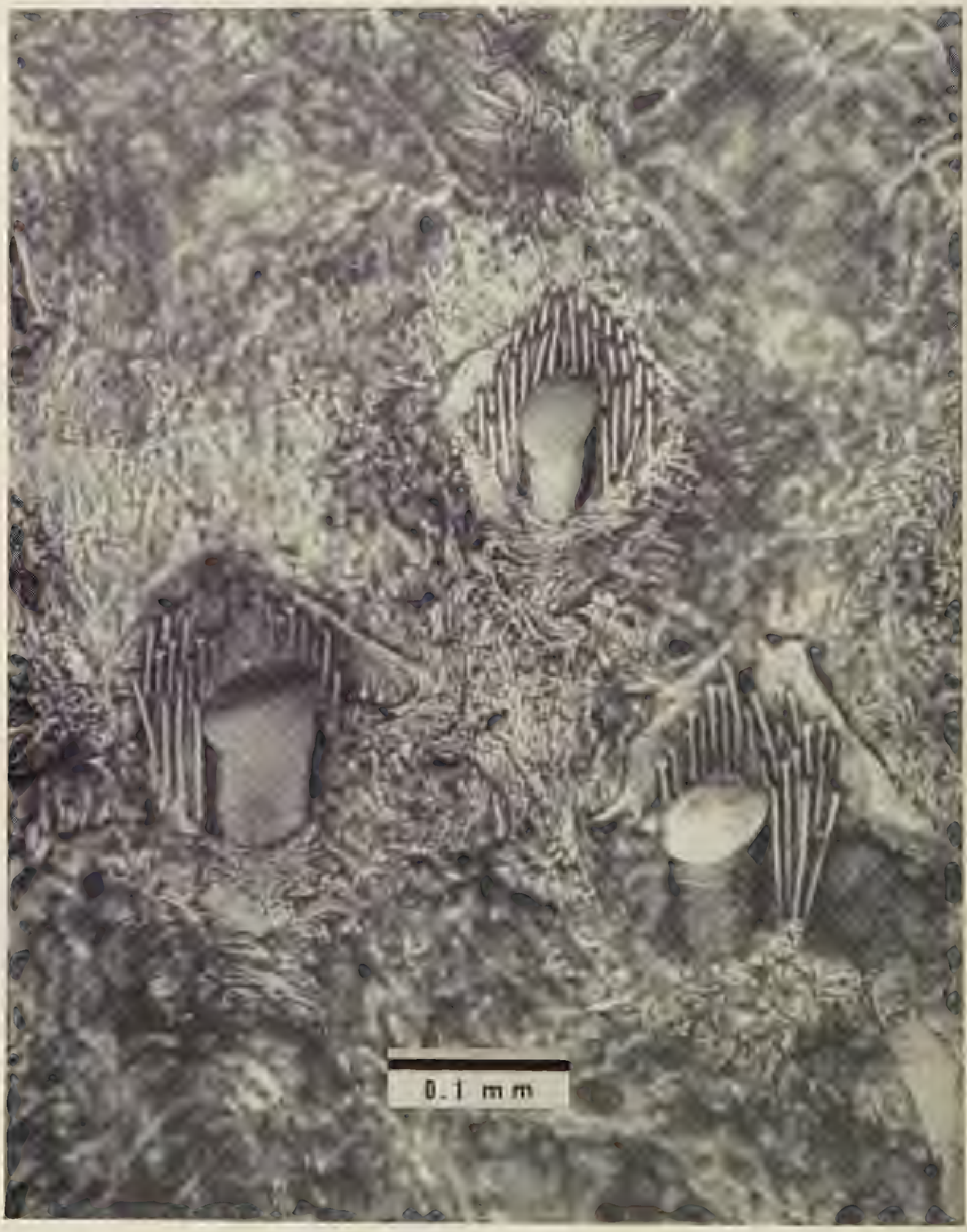

Fig. 3 Thermoplastic impression of sheared surface of the mid-back of a subadult female seal. Three fibre groups are shown, each with a coarse guard hair and from 24 to 31 fine fur fibres behind it. (5290.)

haired area of 0·62 square meters would have approximately 303 million fibres. (The factors 52 and 0·62 are from Scheffer (1962) and from unpublished findings of the author.)

In a variation of the methods described above, tanned, rather than fresh, sealskins have been examined. A patch is sheared from the dry, oil-tanned (chamois dressed) pelt. The surface is daubed with soap lather and is shaved with a razor. From this operational stage onward, the same steps are followed and similar results are obtained. At the conclusion it is of course impossible to express the fibre group count in terms of abundance on the living seal, for the pelt has presumably undergone changes in size and shape during the tanning process.

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Hair Patterns in Seals (Pinnipedia)

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The arrangement, abundance, and size of hairs on the midback region of 44 seals, in 20 species representing the 20 genera, have been studied. Certain minor features of the pelage and skin surface have been noted. The original intent was to test whether variation in hair pattern among seals might have phylogenetic significance and whether it might be used in identifying skin fragments of unknown origin. Identification of fragments is useful in the analysis of stomach contents of marine predators such as the killer whale, polar bear, and large sharks.

De Meijere (1894) examined the grouping of hair in more than 200 mammals, including two pinnipeds. Among more recent authors who have written about hair pattern in seals are: Bergersen ('31), Noback ('51), Mohr ('52), Montagna and Harrison ('57), Sokolov ('59 to '60), Scheffer ('62 to '64), and Scheffer and Johnson ('63). Sokolov's '60 paper reviewed a number of Russian-language articles on skin, leather, and hair.

At the start of the present investigation, hair pattern had been studied in eight of the 20 genera of seals: *Eumetopias*, *Zalophus*, *Callorhinus*, *Odobenus*, *Phoca*, *Pagophilus*, *Erignathus*, and *Cystophora*. It will be helpful to list below six features attributed to adult seal pelage; these have now been found valid for all genera.

1. The hair pattern is made up of units, each containing one coarse hair (primary hair or overhair) and usually a number of finer hairs (secondary hairs or fur hairs). The units are quite uniform in size though not always in spacing.
2. Primary and secondary hairs emerge from a common funnel or skin pore, the primary hair always on the anterior or distal side of the secondary hairs. The bundle of secondaries is situated in the acute angle made by the primary with the surface of the skin.
3. Pressed against the secondaries, the primary hair is usually flattened in cross section. As its growth slows near the end of molt, it becomes rounder and smaller in cross section.
4. Secondary hairs in one group are often of two or three distinct sizes making up a "family."
5. Primary hairs are rooted more deeply than are secondaries.
6. Primary hairs in otariids have a pith or medulla; in walrus and phocids they do not.

METHODS

A procedure was developed in '63 for comparing the hair group patterns of seals (Scheffer, '64). An impression of the sheared surface of the skin is made on transparent thermoplastic film. The impression is then studied in three ways: directly under the microscope (× 100), as a magnified image projected to white paper (× 500), and as a photographic enlargement (× 50). In the present study, however, the '63 procedure was not followed exactly. Controlled-area samples (i.e., delineated on the body of the freshly killed seal) were not available. Some of the present samples are in salt, some are parchment cured, and others are tanned.

Classification of specimens

Forty-four specimens in addition to fetal or young seals in first pelage were examined. The species represented are listed below in the arrangement of Scheffer ('58, p. 42), except that the gray seal is placed near the ringed seal.

---

[1] Many individuals and institutions have donated samples of seal skin or have otherwise helped in the preparation of this report. Only through their generosity have I been able to see samples of skin representing all of the genera of seals.

Because 15 of the 20 genera in the Order Pinnipedia contain but one species the present study of hair pattern expresses differences at more the generic than the specific level. Of the 44 specimens examined no two represent different species of the same genus.

- Order Pinnipedia — pinnipeds
- Superfamily Otarioidea — gressigrade or walking seals
- Family Otariidae — otariids or eared seals
  - Subfamily Otariinae — sea lions
    - *Otaria byronia* — South American sea lion
    - *Eumetopias jubata* — Steller sea lion
    - *Zalophus californianus* — California sea lion
    - *Neophoca hookeri* — New Zealand sea lion
  - Subfamily Arctocephalinae — fur seals
    - *Arctocephalus forsteri* — New Zealand fur seal
    - *Callorhinus ursinus* — northern fur seal
- Family Odobenidae — walrus only
    - *Odobenus rosmarus* — walrus
- Superfamily Phocoidea — reptigrade or wriggling seals
- Family Phocidae — phocids or "earless" seals or hair seals
  - Subfamily Phocinae — nearly all phocids of northern waters
    - *Phoca vitulina* — harbor seal
    - *Pusa hispida* — ringed seal
    - *Halichoerus grypus* — gray seal
    - *Histriophoca fasciata* — ribbon seal
    - *Pagophilus groenlandicus* — harp seal
    - *Erignathus barbatus* — bearded seal
  - Subfamily Monachinae — monk seal and typical antarctic seals
    - *Monachus schauinslandi* — Hawaiian monk seal
    - *Lobodon carcinophagus* — crabeater seal
    - *Ommatophoca rossi* — Ross seal
    - *Hydrurga leptonyx* — leopard seal
    - *Leptonychotes weddelli* — Weddell seal
  - Subfamily Cystophorinae — hooded seal and elephant seals
    - *Cystophora cristata* — hooded seal
    - *Mirounga angustirostris* — northern elephant seal

RESULTS

Based on the best specimen available for study in each species, a table of measurements of adults or subadults is given (table 1). Based on specimens for which age-graduated series are available, another table showing variation in hair pattern with age is given (table 2). An arrangement of diagnostic features of pelage and skin is given in the form of a key (table 3). The key is a first effort; it will be found useful in separating species with quite different hair patterns, though not always in separating species which are similar. Much remains to be learned about hair pattern variation with age and sex.

Spatial arrangement of pelage units

In some species the units are regularly spaced like trees in an orchard (fig. 1). In others the units are arranged in small groups, commonly of two, three, or four (fig. 2). In still others the units are arranged both in groups and in rows (fig. 3). As shown in the key, a regular pattern is characteristic of all otariids, while a group pattern is characteristic of the walrus and all members of the Subfamily Phocinae. Patterns are not consistent in the Monachinae and the Cystophorinae.

Pelage density

The observed range in pelage density, or number of primary hairs per 10 mm^2 of preserved skin, is 18 in an adult male walrus to 115 in an adult female northern fur seal (table 1). The walrus weighed 706 kg; the fur seal was estimated to weigh 50 kg. The difference in their skin surface areas, though not measured, must have been great. Pelage density is obviously a function of surface area. To what extent it is influenced by taxonomic position or inheritance cannot now be judged; though evidence suggests that inheritance does play a part. For example, two specimens listed in table 1 have nearly the same pelage density (35 and 36) but different body weights. One, a harbor seal, weighed 91 kg while the other, a bearded seal, was estimated to weigh 227 kg.

From the evidence of 12 specimens representing four genera, pelage density declines about 60% during postnatal growth of the individual (table 2). Dilution of the hair population as a result of body growth is characteristic of mammals. Szabó ('58) has studied it quantitatively in man.

Size of primary hairs

Maximum hair length varies from 7 mm in a monk seal and an elephant seal to 31 mm in an adult male Steller sea lion. The four seals with longest hairs are male otariids: Steller sea lion, New Zealand sea lion, northern fur seal, and southern fur seal. Here length of hair is perhaps a defense, for male otariids often bite each other during the breeding season.

TABLE 1

Hair patterns of seals: variation with species

Species[1]	Sex	Estimated age	Primary hairs				Secondary hairs				
			Number per 10 mm^2	Maximum length	Mean basal diameter	Ratio of extremes in diameter[2]	Number per unit			Mean basal diameter	Ratio of extremes in diameter[2]
							Minimum	Maximum	Mode		
		years		*cm*	µ					µ	
Otaria byronia	♀	13	53	11	76	1.9	1	3	1	10.0	1.5
Eumetopias jubata	♂	adult	38	31	73	1.5	1	4	1	11.1	4.7
Zalophus californianus	♀	adult	54	9	104	1.9	1	4	1	7.8	2.3
Neophoca hookeri	♂	adult	54	30	161	1.9	1	4	3	19.7	5.3
Arctocephalus forsteri	♂	6–8	73	25	113	2.6	–	–	45	about 7	—[3]
Callorhinus ursinus	♂	12	84	24	102	2.1	–	–	53	10.7	—[3]
Callorhinus ursinus	♀	12	115	18	68	3.0	–	–	45	about 7	—[3]
Odobenus rosmarus	♂	adult	18	7	146	1.4	0	1	0	15.0	2.7
Phoca vitulina	♂	12–15	36	9	158	1.4	3	6	5	28.4	8.4
Pusa hispida	♂	1	50	16	63	2.7	2	4	3	11.7	2.0
Halichoerus grypus	♀	5	37	14	108	2.1	4	7	5	17.9	9.3
Histriophoca fasciata	♂	adult	29	8	144	1.4	2	6	4	17.3	7.3
Pagophilus groenlandicus	♂	adult	28	13	136	1.4	3	5	5	28.6	11.5
Erignathus barbatus	♀	adult	35	10	71	2.0	3	8	7	12.5	10.7
Monachus schauinslandi	♂	20	45	7	125	1.9	0	0	0	0	0
Lobodon carcinophagus	♂	1	94	11	137	1.9	1	4	2	13.3	2.4
Ommatophoca rossi	♀	?	103	13	83	2.8	0	2	1	13.8	3.3
Hydrurga leptonyx	?	?	99	8	180	1.6	1	1	1	30.4	1.9
Leptonychotes weddelli	♀	adult	34	13	91	1.7	2	5	3	30.9	5.4
Cystophora cristata	?	adult	23	15	175	1.5	4	6	5	19.7	7.7
Mirounga angustirostris	♂	3	37	7	204	1.3	0	0	0	0	0

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[1] Each species (and genus) is represented by one specimen selected on the basis of maturity, known sex, and non-molting condition.

[2] Maximum/minimum.

[3] Secondary hairs in the fur seals are too fine to be measured by the method used in the present study. The modal number of secondary hairs per unit in *Callorhinus* is taken from Scheffer and Johnson ('63, table 11).

TABLE 2

Hair patterns of seals: variation with age

Species	Sex	Estimated age	Number of primary hairs per 10 mm² [1]	Number of secondary hairs per unit			Mean basal diameter of primary hairs
				Minimum	Maximum	Mode	
							μ
Odobenus rosmarus	♂	1 (?) year	45	1	3	2	75
	♂	adult	18	0	1	0	146
Phoca vitulina	♀	2–4 (?) months	93	1	5	3	85
	♀	1 (?) year	82	1	2	1–2	75
	♂	1 (?) year	67	2	4	3	83
	♂	adult	52	1	4	3	142
	♂	12–15 (?) years	36	3	6	5	158
Histriophoca fasciata	♂	pup [2]	85	1	4	3	86
	♂	7 (?) months	47	1	3	3	78
	♂	adult	29	2	6	4	144
Erignathus barbatus	♂	pup [3]	86	1	5	3	51
	♀	adult	35	3	8	7	71

[1] Density measured on skin samples preserved by several methods.
[2] About ten days after having shed lanugo.
[3] Age probably less than one month.

The two kinds of seals with shortest hairs breed in warm waters south of latitude 30° N. Water temperature, however, does not seem to influence hair length. Among the seals with nearly the shortest hairs are the ribbon seal and the leopard seal, both adapted to life on ice.

Mean basal diameter of the primary hair varies from 63 μ in a ringed seal to 204 μ in an elephant seal. Perhaps by coincidence, these two kinds of seals also represent extremes in body weight. A relationship between large body size and coarse hair is not confirmed by study of all the data.

Variability in basal diameter of the primary hair also varies with the species. In a northern fur seal, a fine-haired seal, the widest hairs are 3.0 times the diameter of the narrowest (table 1). Conversely, in an elephant seal, a coarse-haired seal, the widest hairs are only 1.3 times the diameter of the narrowest ones. That is, on coarse-haired seals the hairs tend to be more uniform.

On the evidence of four age-graduated series, the mean basal diameter of the primary hair increases with age (table 2). The hair becomes more mature and coarser as the body attains full size. The increase seems to be at least 50%. Uncertainty stems from the fact that the basal diameter of the hair varies as it erupts during molt, and one cannot always obtain a series in comparable stages of molt.

Number of secondary hairs

The count of secondary hairs per unit varies from zero to 50 or more (plate 1).

The count per unit is much higher in the fur seals than in any other seal. Scheffer and Johnson ('63, table 11, p. 21) showed that, in the adult northern fur seal at least, the mean number of secondary *follicles* per unit is only about 15, though the mean number of secondary *fibers* is 45–50. The difference arises from an accumulation of old fibers which remain, unshed from one year to the next, in the unit. The number of secondary follicles per unit in the fur seals is little more than twice that in some hair seals, for example the bearded seal, with seven secondaries per unit.

The sea lions have 1 to 4 secondaries per unit; usually one. In this respect they resemble the Ross seal and the leopard seal, members of another family.

In the present investigation the skins of two adult walruses, both full-grown males, were studied. In both specimens, each skin pore contains a functional primary hair; about one pore in 50 contains a secondary.

TABLE 3

Key to genera of seals based on features of the pelage and skin (see table 1)

Genus	Primary hairs		Maximum length of primary hairs, cm		Mean basal diameter of primary hairs, microns		Primary hairs spaced		Modal number of secondary hairs per unit			Mean basal diameter of secondary hairs, microns		Color of epidermis	
	Medullated	Nonmedullated	7–11	13–31	63–104	108–204	Uniformly	In groups	0	1–7	> 10	7–12	13–31	Light	Dark
Otaria	X		X		X		X			X		X		X	
Eumetopias	X			X	X		X			X		X		X	
Zalophus	X		X		X		X			X		X		X	
Neophoca	X			X		X	X			X			X	X	
Arctocephalus	X			X		X	X				X	X		X	
Callorhinus	X			X	X		X				X	X		X	
Odobenus		X	X			X		X	X					X[1]	
Phoca		X	X			X		X		X			X		X
Pusa		X		X	X			X		X		X			X
Halichoerus		X		X		X		X		X			X		X
Histriophoca		X	X			X		X		X			X		X
Pagophilus		X		X		X		X		X			X		X
Erignathus		X	X		X			X		X		X			X
Monachus		X	X			X	X		X						X
Lobodon		X	X			X	X			X		X			X
Ommatophoca		X		X	X			X		X		X			X
Hydrurga		X	X			X	X			X		X			X
Leptonychotes		X		X	X			X		X		X			X
Cystophora		X		X		X		X		X		X			X
Mirounga		X	X			X	X		X						X

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[1] Dermal papillae present (p. 299).

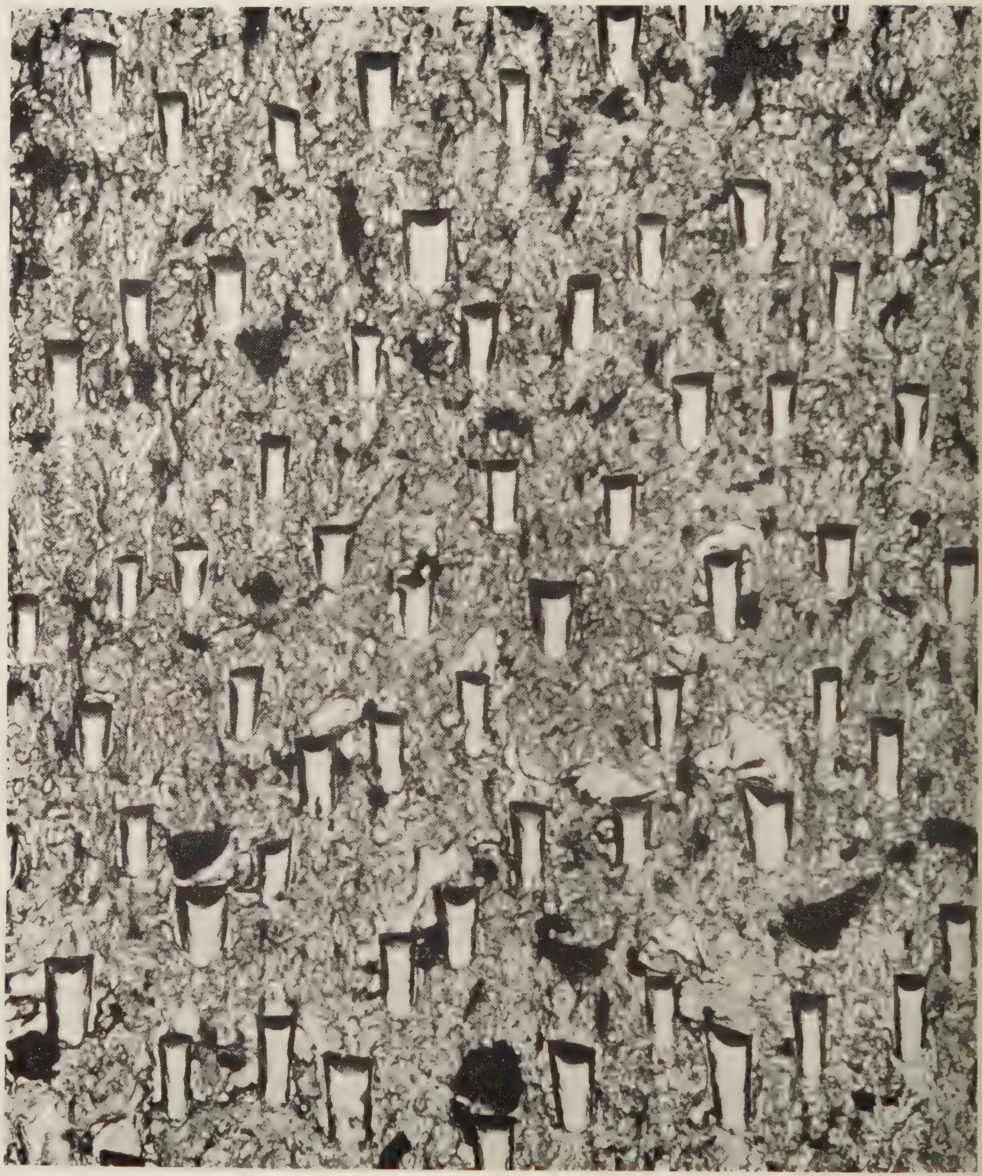

Fig. 1 Impression (× 50) of sheared tanned skin of California sea lion (*Zalophus californianus*). old adult female, nonmolting. (5360).

The modal number of secondaries per unit among the phocids varies from 0 to 7. In the skin of two elephant seals, one of them about ten months old and the other about three years, no secondaries are visible. In the skin of a monk seal about three years old no secondaries are visible, while in the skin of another about 20 years old, only one secondary per 50 units ca be seen. The two phocids, elephant sea and monk seal, which have virtually no secondary hairs, are also the two with shortest primaries

Among the other phocids — those tha have from 1 to 7 secondaries per unit — a weak relationship between abundance of

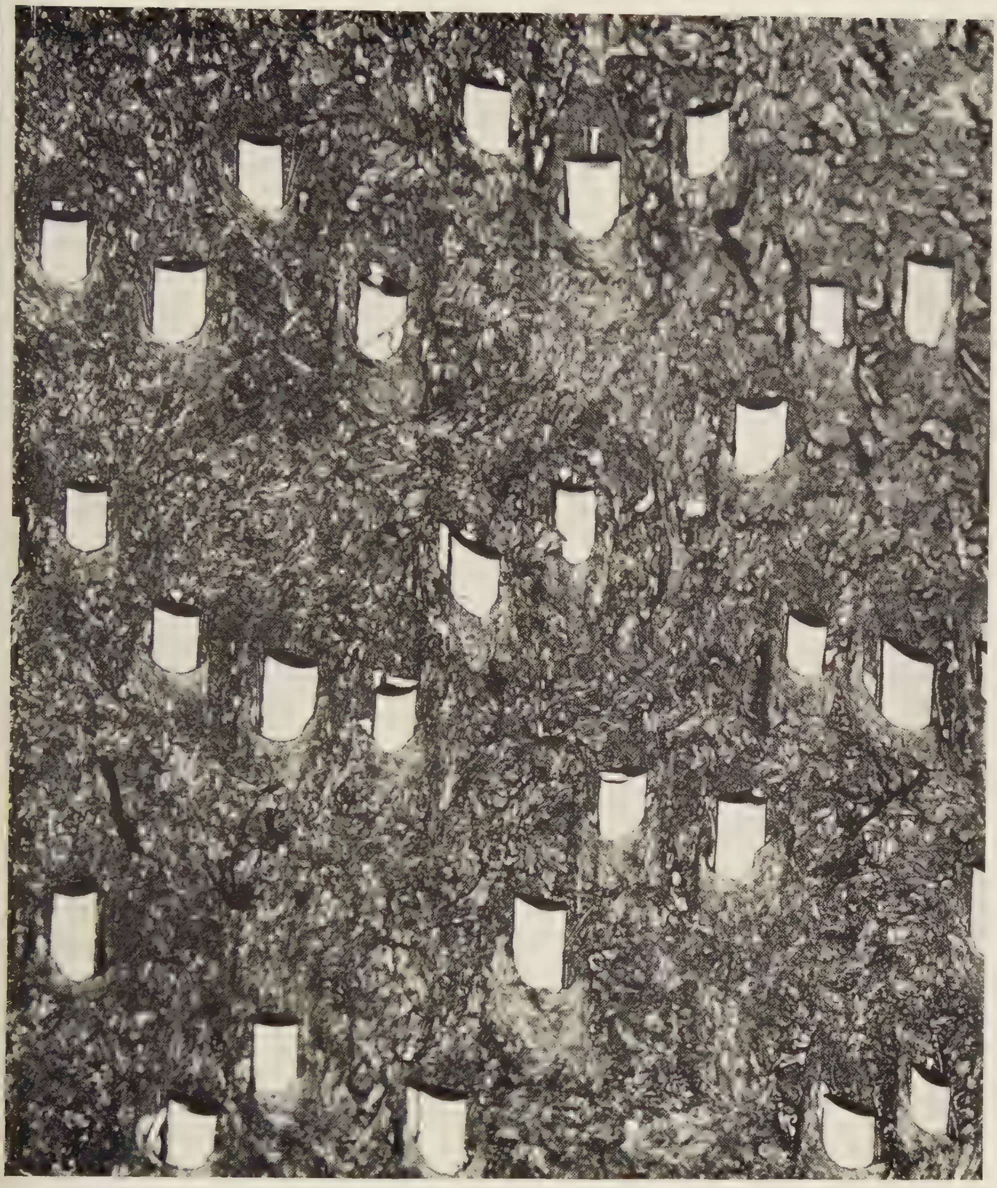

Fig. 2 Impression (× 50) of sheared tanned skin of ribbon seal (*Histriophoca fasciata*), adult le in ending molt. (5357).

condaries and phylogenetic position can seen. The six species which compose e Subfamily Phocinae have a modal unt of three or more secondaries per it, though among them are two seals ich are phylogenetically out of place: oded seal (Subfamily Cystophorinae) d Weddell seal (Subfamily Monachinae).

The leopard seal is distinctive in having one very coarse secondary per unit.

As already stated, in the northern fur seal and probably in the southern fur seal secondary hairs increase in abundance with age of the seal as a mechanical result of delayed shedding. In the walrus, secondary follicles atrophy with age, leav-

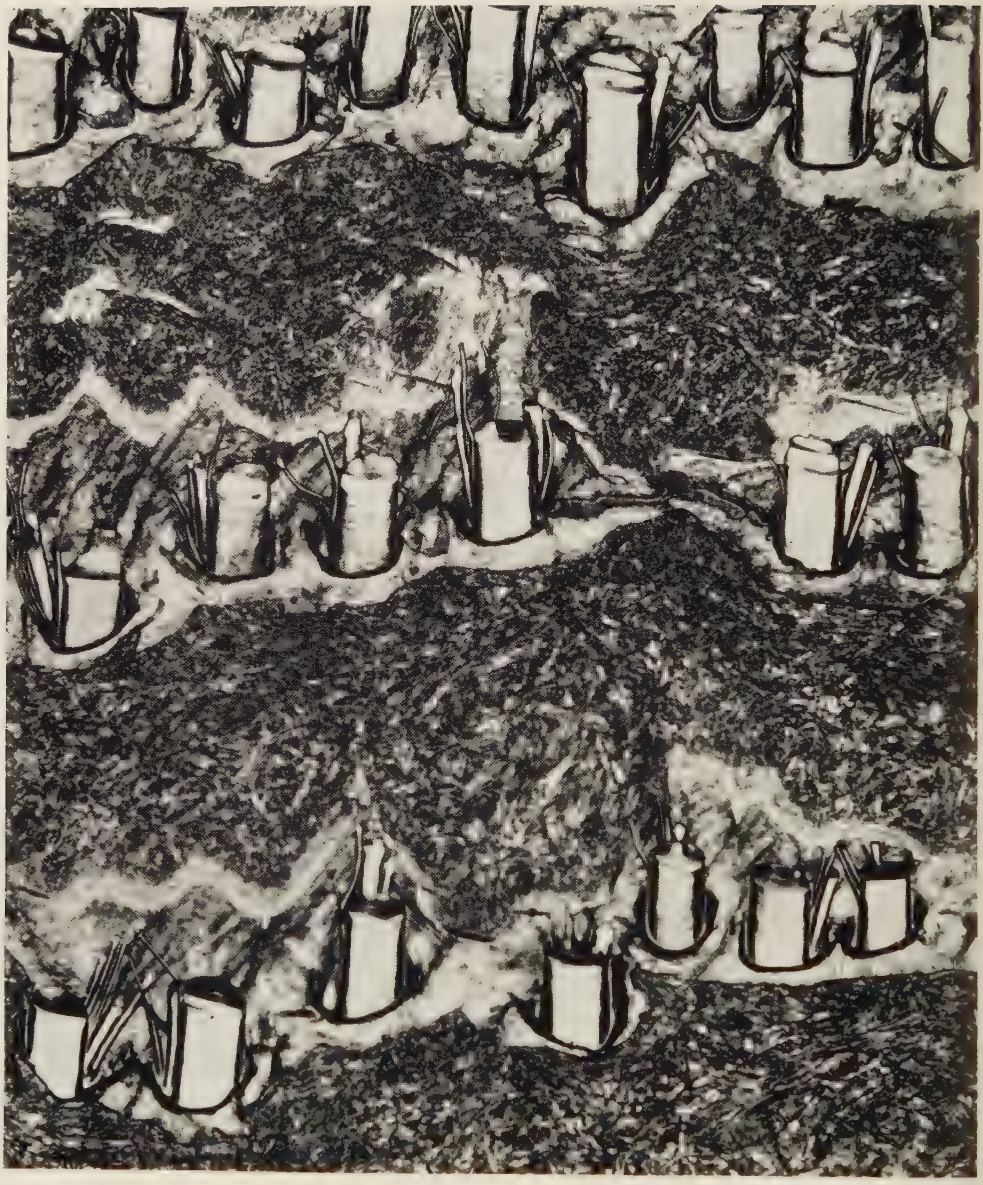

Fig. 3 Impression (× 50) of sheared tanned skin of hooded seal (*Cystophora cristata*), probably adult, in ending molt (5521A).

ing an adult skin which is almost naked. In phocid seals secondary hairs may (?) accumulate with age. Among three species of phocids for which an age-array of specimens is available, the oldest individuals have the highest counts of secondary hairs (table 2).

Changes in secondary hair count with age are perhaps obscured by individual and sex variation. Two yearling harbor seals were nearly the same length (115 and 110 cm), were taken at the same time and place, and were nonmolting. For one of them (female) the mean count of secdaries per unit is 1.5 and for the other ale) it is 3.2. The difference is perhaps nutritional effect. Hardy ('51, p. 491) ported that in lambs “the potential group e [of secondary hair rudiments] is ongly inherited, but the actual group e (number of active follicles) in the ature animal varies according to the food take in the first year of life.”

Basal diameter of secondary hairs

The mean basal diameter of secondary irs varies from about 7 μ in the fur seals over 30 μ in the Weddell and leopard als. The otariids have fine underhairs; e walrus has virtually none; the phocids, th two exceptions, have coarse under- irs. Exceptions are the ringed seal, allest of the pinnipeds, and the bearded al. The bearded seal resembles the fur als in having many secondary hairs per it.

On a given specimen, the secondary irs vary more in diameter than do the imary hairs. For secondaries, the ratio extremes reaches 11.5; for primaries, 0 (table 1).

The length of secondary hairs was not easured. These hairs are delicate and rly; it would be impractical to measure eir length for diagnostic purposes.

Minor features

Only the primary hairs of otariids have pith or medulla. Noback ('51) con- uded that presence of a medulla is corre- ted with large diameter and not with the xonomic group of the animal possessing e hair. In seals, this is half true. While secondary hairs are nonmedullated, me large primary hairs of phocids are so nonmedullated. For example, the ean basal diameter of the primary hairs the northern elephant seal is 204 μ and e hairs are nonmedullated, while the ameter of certain hairs of the northern r seal is only 100 μ, yet the hairs are stinctly medullated.

The epidermis of all otariids and the lrus is whitish or light gray. The epi- rmis of all phocids is distinctly brown black. The epidermis of all seals has a aly relief. The scales are more promi- nt where the pelage units are in rows, in the hooded seal and walrus (figs. 3 and 4). Scale pattern is not a good diagnostic feature for separating genera.

A unique interface between dermal and epidermal layers characterizes the skin of the walrus. Conspicuous dermal papillae extend into epidermal pockets, as described by Sokolov ('60, p. 286). A pelage sample shaved just below the surface of the skin may show pimpled areas, each pimple being the cross section of a dermal papilla (fig. 4). The papillary arrangement is not visible in the skin of two immature specimens in the present collection: a fetus and a five-month-old; it is visible in the skin of a yearling and two adults.

DISCUSSION

Hair pattern among seals is even more monotonous than De Meijere (1894) found it among land carnivores, no doubt because of the monotonous aquatic environment of seals. As insulation against cold water all seals have developed a thick layer of blubber; pelage has lost importance as a body coating, except in the fur seals. Also, the fact that hair-erecting muscles have not been demonstrated in seals but are present in carnivores suggests that seal pelage has lost a primitive ability to vary its insulating capacity.

The “basic trio” (Noback, '51, p. 476), long regarded as the primitive group-pattern of mammalian hair, is not evident in the pelage of seals (figs. 1–4).

Primary hairs have persisted in all seals. They are more conservative and they exhibit less variability than do secondary hairs. Secondary hairs are often vestigial, as in the walrus, while in the monk seal and elephant seal they have practically disappeared.

The epidermis is even more conservative than the primary pelage. It still points to main phylogenetic stems. The color of the epidermis is the only character which consistently enables one to separate the Otarioidea, with light skin, from the Phocoidea, with dark skin.

Spatial arrangement, abundance, and size of hairs of the midback are specific characters, though several species of seals have similar sets of characters. It is puzzling to note that seals unlike in presumed origin, and certainly unlike in present mode of life, may have similar hair pat-

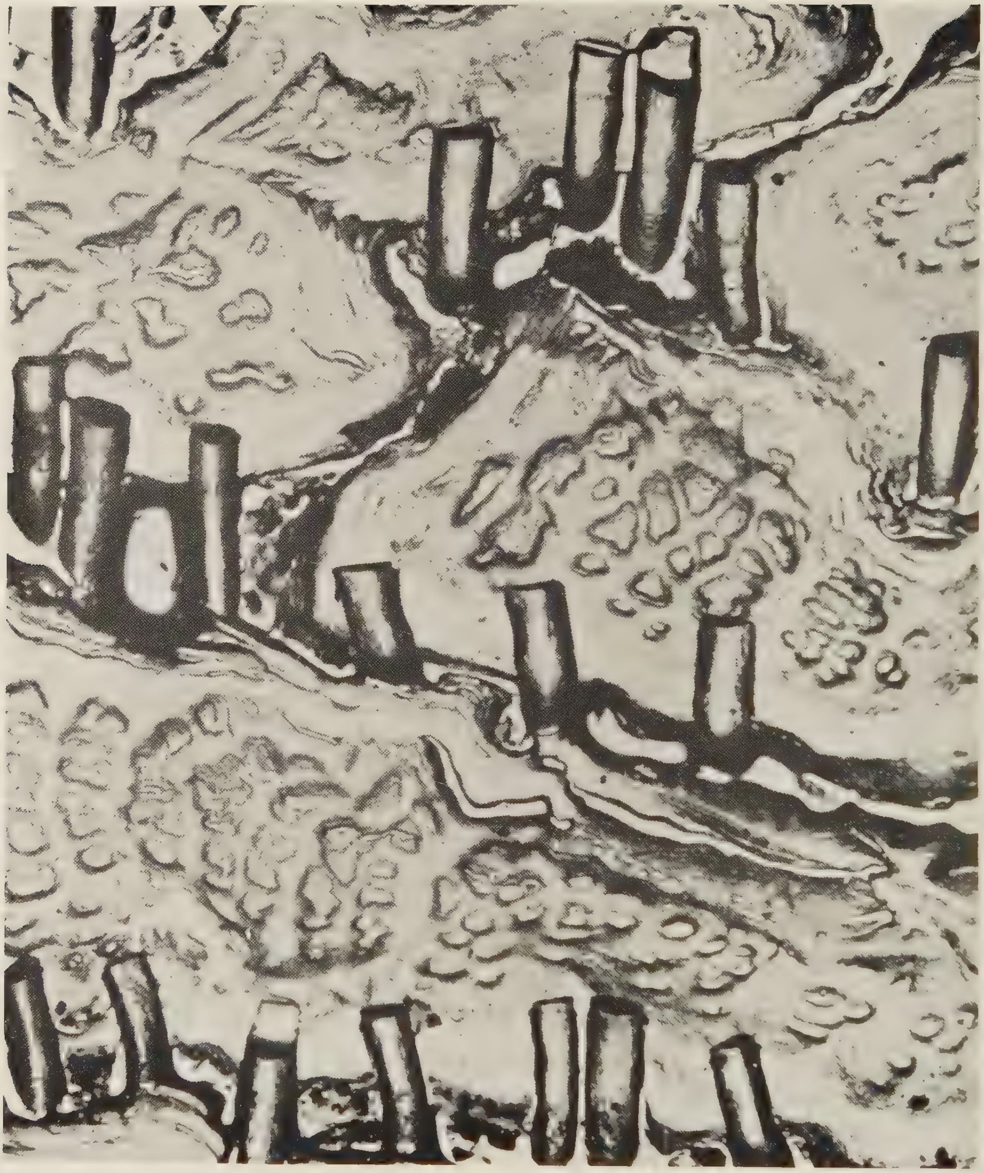

Fig. 4 Impression (× 50) of formalin-preserved skin of walrus (*Odobenus rosmarus*), adult male, nonmolting (5584).

terns. This is true of the sea lions of temperate waters vis-a-vis the crabeater and Ross seal of the coldest waters in the world. The answer to the puzzle is perhaps parallel evolution, or convergence.

Also puzzling is the observation that seals belonging to the same family and sharing the same general environment may have very different hair patterns. Sea lions are genetically so close to fur seals that the two will interbreed in captivity, yet their hair patterns are distinct.

Among the Pinnipedia are four paired genera. Each pair is thought to represent a terminal forking of a branch of the family tree. The two members of each pair always have separate geographical ranges. In the following pairs, the first member ranges in the northern hemisphere, the second in the southern:

Larger sea lions, *Eumetopias* and *Otaria*.

Smaller sea lions, *Zalophus* and *Neophoca*.

Fur seals, *Callorhinus* and *Arctocephalus*.

Members of another pair range in the North Atlantic and North Pacific, respectively:

"Banded" seals, *Pagophilus* and *Histriophoca*.

While it has long been known that the members of each pair resemble one another in gross morphology, it is now clear from table 1 that they also resemble one another in hair pattern.

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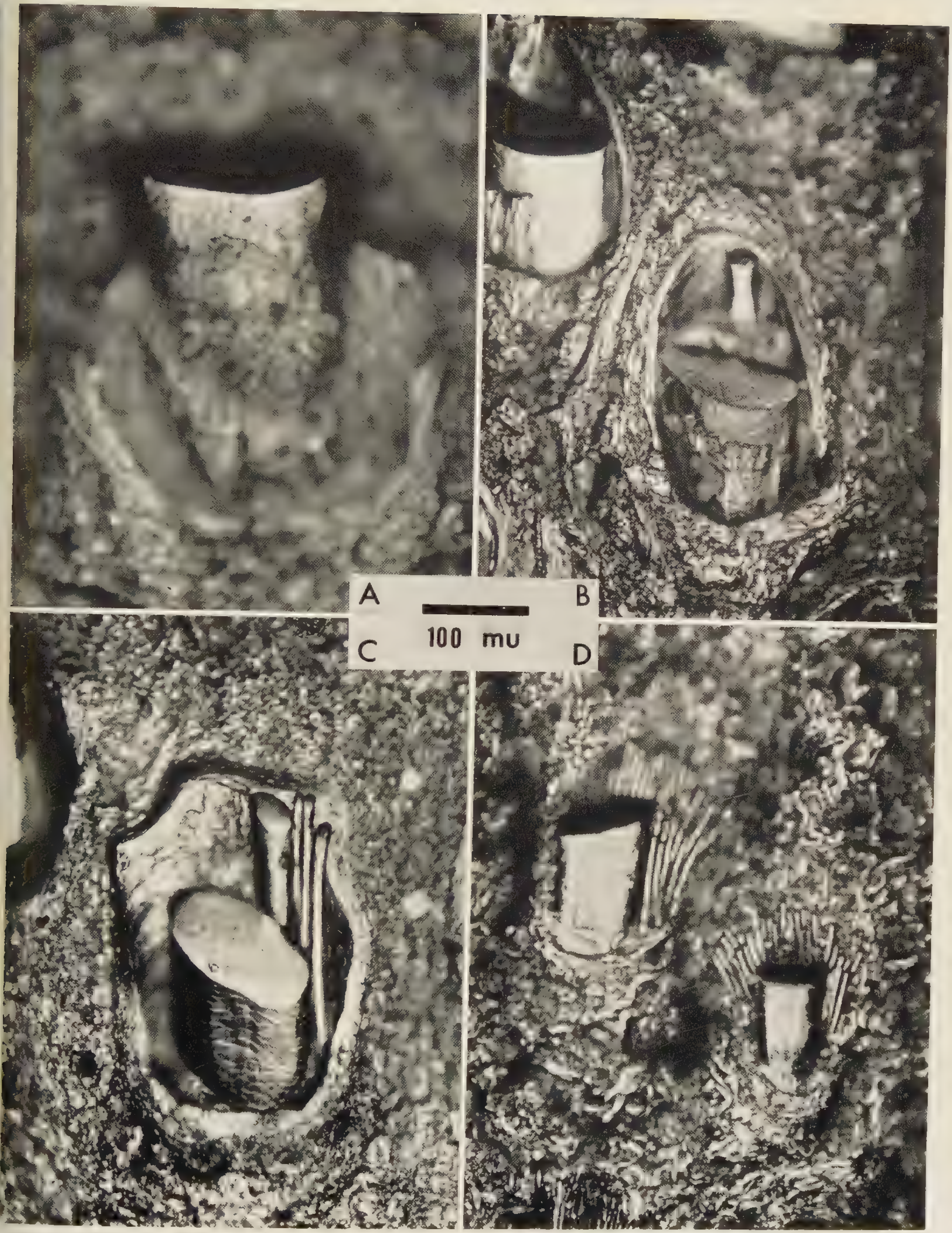
PLATE 1

EXPLANATION OF FIGURES

Variation in number of secondary hairs per pelage unit. (A) None in elephant seal (*Mirounga angustirostris*). (B) One in leopard seal (*Hydrurga leptonyx*). (C) About three to five in harp seal (*Pagophilus groenlandicus*). (D) About 45 in northern fur seal (*Callorhinus ursinus*). (5570–5573).


A
B
C
D
100 mu

Environmental Radioactivity in Molluscs

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Jo-Ann Lewis, *Bureau of Commercial Fisheries,
Radiobiological Laboratory, Beaufort, N. C.*

In three species of molluscs, Ce^{144}, Ru^{106}, Zn^{65}, Mn^{54}, Cs^{137}, Zr^{95}-Nb^{95}, and K^{40} have been detected during a survey of the radioactivity existing at the present time in the estuarine environment. These molluscs were hard clams, *Mercenaria mercenaria;* oysters, *Crassostrea virginica;* and bay scallops, *Aequipecten irradians.* The gamma radioactivity was determined with a low background detecting system consisting of a large shield, a 4 × 4 -inch NaI(Tl) crystal, and a 512-channel analyzer. In clams and oysters most of the activity was due to Ce^{144}, Ru^{106}, Zn^{65}, and K^{40}. Scallops contained at least ten times more activity than clams or oysters, this being primarily Mn^{54}. Results of experiments have shown that these three molluscs accumulate similar amounts of Mn^{54} from sea water in the laboratory; therefore, to explain the differences in the distribution of this isotope among naturally occurring populations poses an interesting ecological problem.

Abstract reprinted from the *ASB Bulletin,*
Vol. 11, No. 2, p. 55, April 1964.

23. Climatic Oceanography and its Application to the Hawaiian Skipjack Fishery

There are changes in the temperature and salinity of the ocean's waters which are analogous to changes in temperature and humidity in the atmosphere. Just as the latter can be explained in terms of movement of air masses, weather fronts, and circulatory systems, so the analogous changes in the ocean can be related to the movements of fronts which separate different water types or water masses. The boundary between the North Pacific Central water and the California Current Extension water moves seasonally through the region of the Hawaiian Islands. The time or northward movement of the boundary in late winter, as reflected in the time of initial warming of the sea near Oahu, and the presence of California Current Extension water around the Islands during the summer months have been shown to be related to the success of the Hawaiian skipjack fishery. Consequently, the time of initial warming early in the spring can be used to predict the relative success of the summer skipjack fishery.

GUNTER R. SECKEL
U. S. Bureau of Commercial Fisheries

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SEASONAL GONADAL CHANGES IN FEMALE SOFT-SHELL CLAMS, *MYA ARENARIA*, IN THE TRED AVON RIVER, MARYLAND

WILLIAM N. SHAW

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SEASONAL GONADAL CHANGES IN FEMALE SOFT-SHELL CLAMS, MYA ARENARIA, IN THE TRED AVON RIVER, MARYLAND

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ABSTRACT

Changes in the gonad of female soft-shell clams were observed at regular intervals from May 1961 through May 1962. From May to August 1961 ovaries consisted of follicular cells with many inclusions and no gametogenesis was seen. In August gametogenesis began and small ovocytes were observed developing. By late September most clams had mature ova. Spawning began around September 27 and continued through October. A second cycle of gametogenesis started shortly after fall spawning was completed. Histological examination revealed that ovocytes in many clams were half-grown by March 1962, but failed to grow to maturity. Most ovocytes underwent cytolysis, and by May 1962 clams were in the summer or inactive stage as in the summer of 1961. Mature ova were found in a few clams, but no clam reached the degree of ripeness found in autumn 1961. Lack of Mya larvae and set support the conclusion from gonad examinations, that Tred Avon River clams failed to spawn or to produce viable larvae in the spring of 1962.

INTRODUCTION

Seasonal changes of the gonad of many species of pelecypods have been described, including the northern quahog, Mercenaria mercenaria, by Loosanoff (1937); the eastern oyster, Crassostrea virginica, by Loosanoff (1942); and the European oyster, Ostrea edulis by Loosanoff (1962). Only incomplete information is available on the seasonal gonadal cycle of the soft-shell clam, Mya arenaria. Rogers (1959) gave a brief description of the fall changes that occur in the gonad of Mya, but he failed to complete the yearly cycle. Coe and Turner (1938) describe in detail the development of the gonad of Mya, but mention only briefly the seasonal changes.

It appears that north of Cape Cod Mya spawns once a year, while south of Cape Cod it spawns twice a year. Landers (1954) found peaks of abundance of Mya larvae in Narragansett Bay, Rhode Island, in the spring and in the fall. He noticed that spawning ceased during late summer. In Maryland, Pfitzenmeyer (1957) observed a successful set of Mya in October 1956 and again in May 1957, and reported that in previous years spring spawning was known to have occurred with little successful setting, so that the annual set appeared to be a result of autumn spawning. Manning (1957) reported that the Maryland soft-shell clam sets during the autumn. In a more recent paper, Pfitzenmeyer (1962) found setting in both spring and fall in 1957, 1958, and 1959. He theorized that the two peaks of spawning of the soft-shell clam each year in Maryland are the result of two separate periods of gonadal maturation, and not one period interrupted by temporary cessation.

The purpose of this paper is to describe the seasonal cycle of gonad development of the female soft-shell clam in the Tred Avon River, Maryland. Histological study has shown for the first time that in Maryland there are two separate periods of gonadal development each year. This study is part of a project concerned with the ecology and distribution of clams and oysters in local waters.

METHODS

The Tred Avon River is about 10 miles long, beginning near the town of Easton and emptying into the Choptank River which in turn flows into Chesapeake Bay. In the mouth of the Tred Avon there are several clam beds which are fished commercially with hydraulic dredges.

Salinity, temperature, and amount of dissolved oxygen (Fig. 1) were measured in front of the Oxford laboratory in seven feet of water. Temperature was recorded daily by a thermograph while salinity and amount of dissolved oxygen were recorded weekly. Salinities fluctuated from a low of 8.02 ppt on 26 July 1961, to a high of 15.52 ppt on 26 December 1961. In general, lower salinities were found in summer than in winter. During the first four months of 1961, the salinity averaged 2.25 ppt lower than during the corresponding period in 1962. Temperatures ranged from a low of -0.5 C on 26 January 1961, to a high of 30.0 C on 23 July 1961. Amount of dissolved oxygen followed a normal seasonal pattern with highest readings occurring in winter (13.46 ppm) and lowest readings in summer (4.55 ppm). No deficiencies in amount of dissolved oxygen were found during the study.

Mya was first sampled 19 January 1961. Because the river was frozen over, only sporadic samples were taken during February and part of March. Starting in May sampling was done each week and continued without interruption until 18 May 1962, when the first phase of this study was terminated.

Each sample, consisting of ten clams two inches or more in length, was collected from a shallow bottom opposite the Bureau of

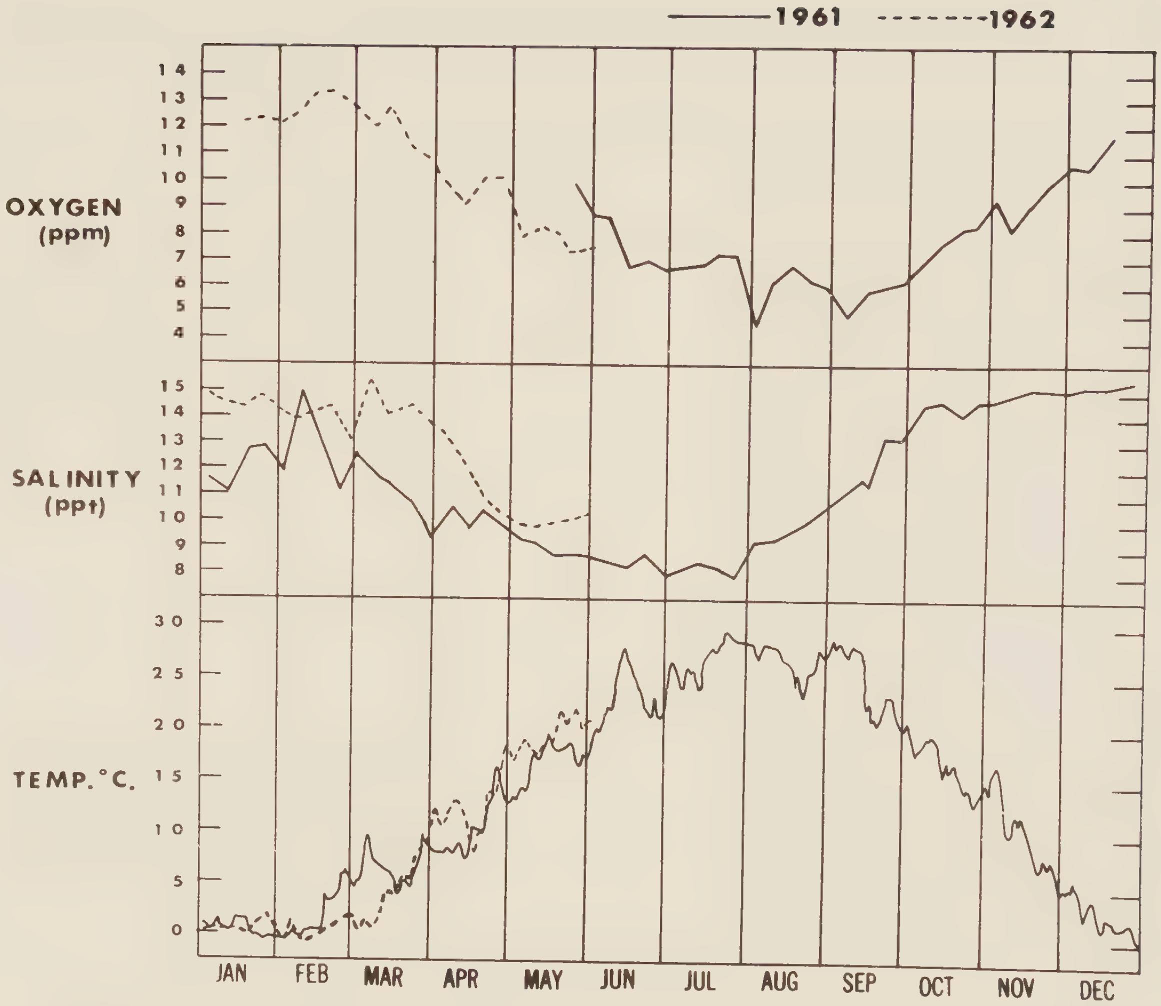

Fig. 1. Water temperature, salinity, and amount of dissolved oxygen for the Tred Avon River, Maryland.

Commercial Fisheries Laboratory. The clam meats were fixed in Kahle's fluid (Guyer, 1953), dehydrated in alcohol, changed to xylene, embedded in paraffin, and sectioned at about 8 microns with a razor blade mounted on a standard rotary microtome. Sections were stained in Harris' or Delafield's hematoxylin and eosin. A total of 607 clams were processed over a continuous period of 17 months. Of these, 306 or 50.4% were males, and 301 or 49.6% were females. No hermaphrodites were found. In this phase of the study only the female clams were examined. The seasonal gonadal changes of the male will be covered in a later publication.

Weekly plankton samples were taken at four stations in the Tred Avon River from 23 June to 30 November 1961, and from 11 April to 30 June 1962, in order to determine when planktonic Mya larvae first appeared, when they were most abundant, and when they disappeared. Bottle collectors like those used by Thorson (1946) were placed at the same stations to determine when Mya was setting. These bottles were replaced every 15 to 30 days from 28 June to 7 December 1961, and again from 11 April to 16 July 1962.

RESULTS

Following Loosanoff (1942), I have divided the seasonal cycle into several stages: summer or inactive, active, mature, partially spawned, and completely spawned.

Summer or Inactive Stage

Examination of female clams collected in the latter part of May 1961, and again in May 1962, showed each alveolus consisting of follicular cells with many inclusions (Fig. 2). Those ovocytes present were degenerating and undergoing cytolysis. Coe and Turner (1938) state that the inclusions are reserve nutritive substances derived in part from the cytolysis of degenerating ovocytes. It was observed that some inclusions stained bright blue and showed no traces of eosin, while others were bright red. There is need for further investigation of these bodies. The clams remained in the summer or inactive stage until August.

Active Stage

Early in August active gametogenesis began. Small ovocytes were observed at the base of the alveolar walls (Fig. 3). Gametogenesis progressed at a rapid rate during August, and by the end of the month

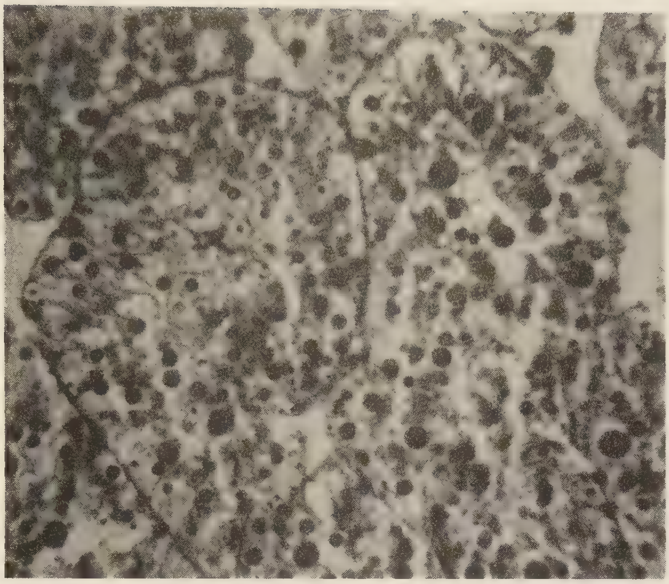

Fig. 2. Summer or inactive stage. Follicle cells with dark bodies called inclusions. No ovocytes present. June 1961. X 200.

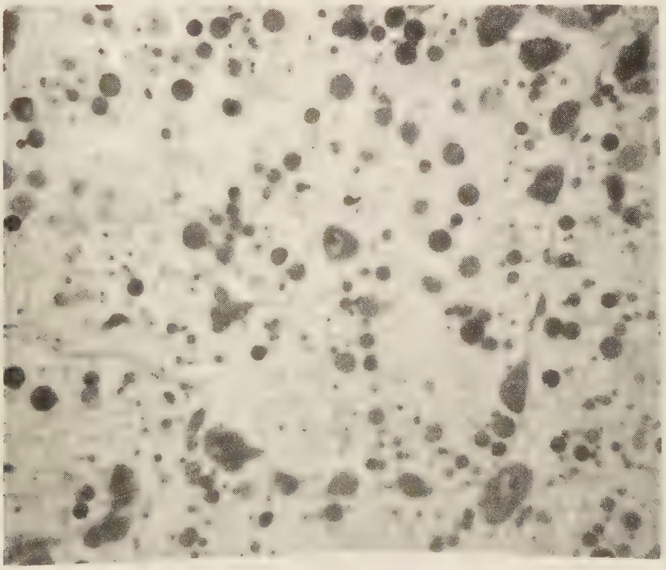

Fig. 3. Female clam with young ovocytes. August 1961. X 200.

many ovocytes were half-grown and attached to alveolar walls by stalks (Fig. 4). By the end of the first week in September a few ova had reached maturity and appeared free in the lumen. The follicular cells were then undergoing cytolysis and inclusions were much less numerous. Coe and Turner (1938) state that these inclusions supply the nourishment for the rapidly growing ova.

Mature Stage

In 1961 the majority of clams examined were mature by the last week in September or the first week in October. Each alveolus now contained many mature ova which appeared to be free in the lumen or attached to the alveolar walls by slender stalks (Fig. 5). The follicular cells were gone and only a few inclusions were present. The mature ova measured about 60 microns. Each ovum had a large nucleus and the nucleolus (amphinucleoli, Wilson, 1925) was divided into two zones, the smaller of which stained much darker.

Partially Spawned Stage

Evidence of spawning was first observed on 27 September. As shown in Fig. 6, the number of mature ova present in each alveolus of a partially spawned clam ranged from 0 to 8. Those alveoli that no longer had ova were collapsed.

Completely Spawned Stage

By the first of November all clams examined were spawned out. Only a few unspent ova could be found. The alveoli had collapsed and only a few inclusions were still present. In general, each alveolus now consisted of a single row of cells (Fig. 7). At the corresponding stage in *M. mercenaria*, Loosanoff (1937) found few if any phagocytes in the lumen. He believed that the undischarged ova showed no indication of being decomposed and suggested that these eggs are extruded later in the normal manner. *Mya* appeared to be similar to *Mercenaria* in this respect since no phagocytes were found after spawning and the unspent eggs showed no indication of being broken down.

Second Cycle of Gametogenesis

Coe and Turner (1938) reported that during the autumn and winter at New Haven, Connecticut, the gonad of *Mya* consisted of follicular cells with an accumulation of inclusions. In Maryland, however, the

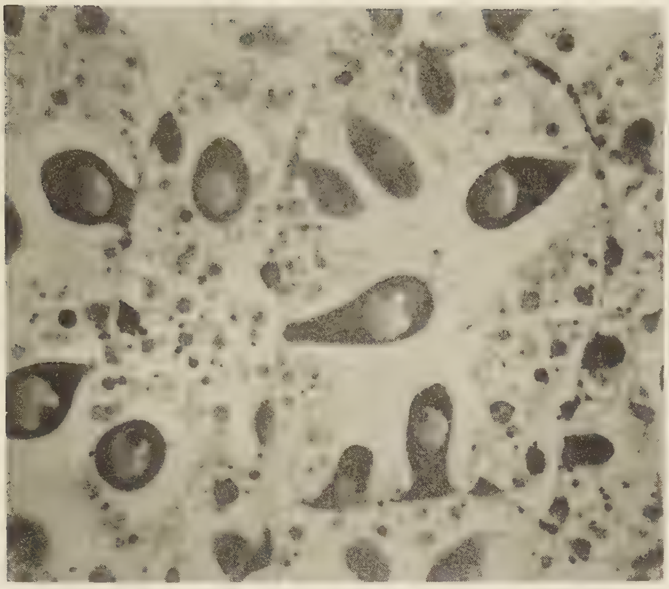

Fig. 4. Active gametogenesis. Ovocytes half-grown with stalks. September 1961. X 200.

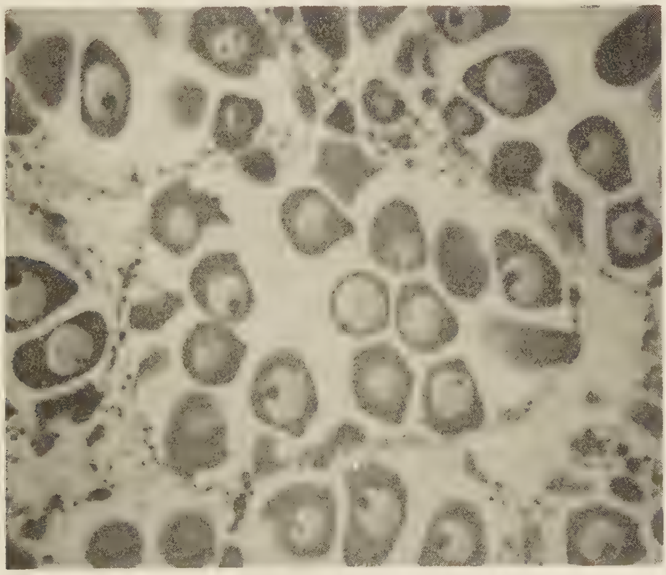

Fig. 5. Ripe female clam. October 1961. X 200.

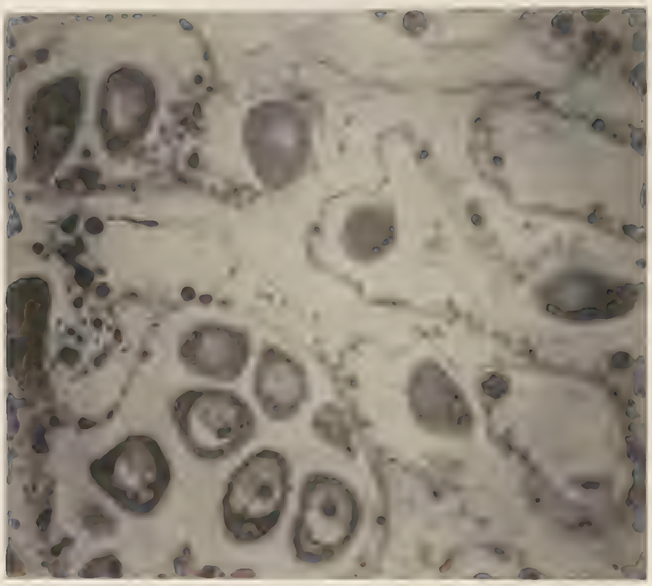

Fig. 6. Partially spawned out clam. October 1961. X 200.

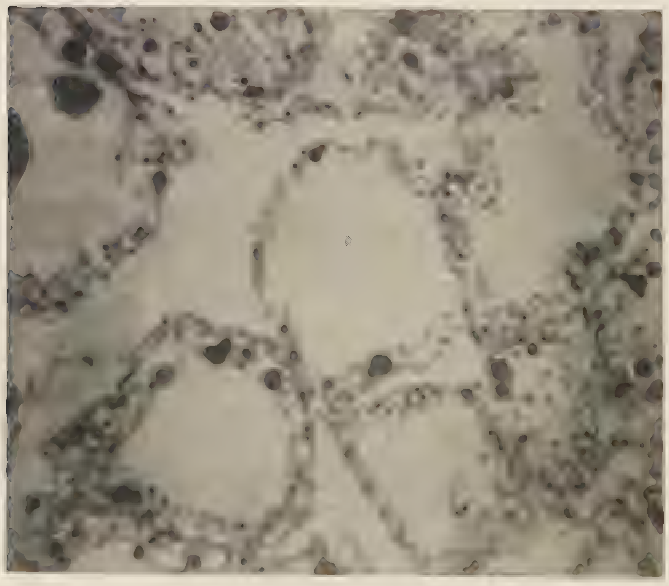

Fig. 7. Spawned out female clam. November 1961. X 200.

corresponding stage was observed during summer but not during autumn and winter. Instead, shortly after spawning was completed in November, small ococytes were developing along the base of the alveolar walls (Fig. 8). Lacking, though, were the numerous inclusions that were so prevalent in the early stages of gametogenesis in August 1961 (Fig. 3).

By January 1962, the clams were found in different stages of gonadal development. Many were in a stage similar to that observed in November 1961 (Fig. 8) with only small ovocytes along the inner walls of the alveoli. In other clams the ovocytes were half-grown (Fig. 9). There was no apparent ecological basis for these differences since all clams were collected from the same locality.

During February and March little further development was observed. The water temperature for most of this period was below 5 C (Fig. 1) and the clams' metabolic rate was probably reduced. Loosanoff (1937) observed that Mercenaria enters hibernation when the water temperature falls below 5 C and gametogenesis is considerably reduced during this time.

During April 1962, instead of an expected rapid gonadal development corresponding with an increase in water temperature, the ovocytes underwent cytolysis. The clams began to show characteristics of the summer or inactive stage (Fig. 2) rather than developing to maturity. In a few clams some mature ova were found, but in no case did any of the clams examined reach the degree of maturity found in the fall of 1961. By May 1962 all clams were in the summer or inactive stage with only remnants of ovocytes (Fig. 2). From histological examination, there was no evidence that spawning had occurred in the Tred Avon River in the spring of 1962.

Examination of Plankton and Contents of Bottle Collectors

Mya larvae were first observed in the plankton on 28 September 1961. This period corresponded very closely to the time when indications of spawning were observed in histological sections. The peak abundance of larvae was on 20 October, and the last larvae were found in the plankton on 22 November. No Mya larvae were found in the plankton in the spring of 1962.

The first set of Mya in the bottle collectors was observed on 20 October. These bottles had been in the water since 28 September 1961. The greatest number of Mya spat (35) was found in a bottle that was in the water from 5 October to 7 November. Only two Mya had set in the bottles that were in the river from 7 November to 7 December. No Mya set were found in the bottles that were placed in the river in the spring of 1962.

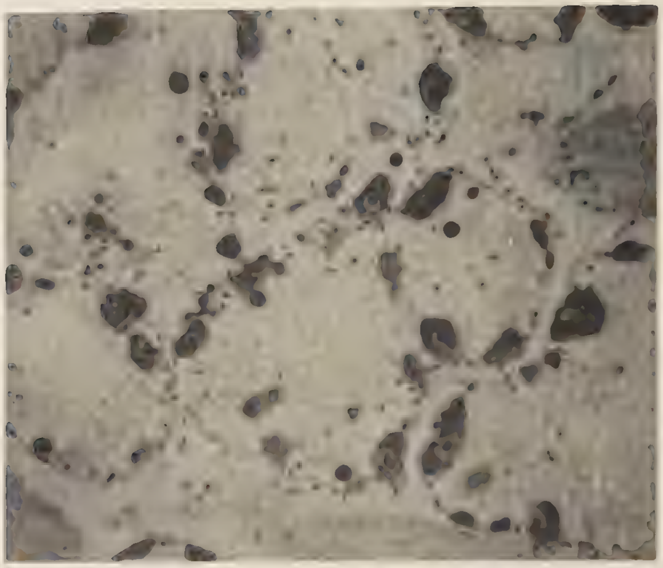

Fig. 8. Early gametogenesis of second cycle. Only a few inclusions are present as compared to same stage in fall of 1961. November 1961. X 200.

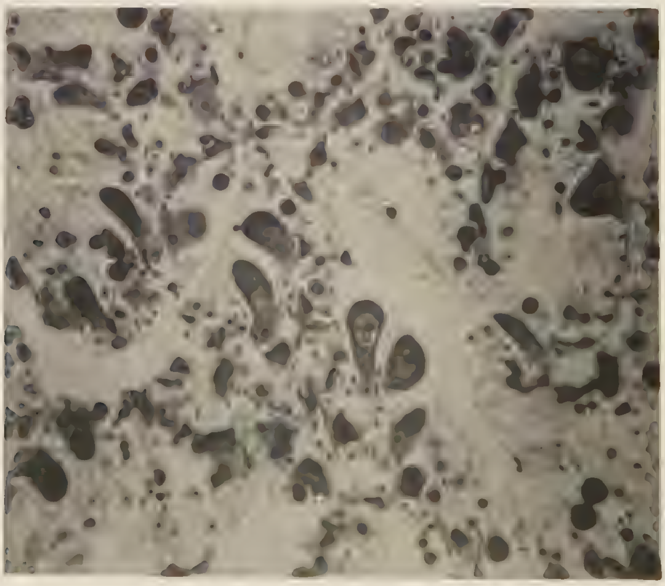

Fig. 9. Female clam with partially developed ovocytes. Majority of clams reached this state in the spring and then the ovocytes underwent cytolysis. March 1962. X 200.

DISCUSSION

Examination of the seasonal cycle of M. arenaria in Maryland reveals that there are two cycles of gonadal development each year. Though the spring cycle did not reach maximum development in 1962, there is evidence (Pfitzenmeyer, 1962) that in past years successful spawning has occurred in both spring and fall.

From histological examination there is definite evidence that the two spawning cycles actually involve two different gonadal maturations. The summer or inactive stage which separates the two cycles appears to correspond with the period in the life cycle of the oyster which occurs just prior to hibernation, when the organism has stored a considerable amount of glycogen to carry it over the winter. Further studies are necessary to determine if inclusions in clams are actually bodies of stored glycogen.

Loosanoff (1942) found in Crassostrea virginica an indifferent stage at which time sex reversal takes place. However, Loosanoff (1937) did not find such a stage in the female M. mercenaria, and he stated that sex reversal seldom occurs in the quahog. Mya was found to be similar to M. mercenaria in this respect. At no time during the female gonadal cycle was there a period of indifference when the sex was in doubt. It therefore seems unlikely that sex change from female to male occurs in the soft-shell clam.

Close examination of the two cycles that occur in Maryland indicates that the inclusions, which are so abundant during the summer, are supplying a good part of the nourishment (Coe and Turner, 1938) for the developing ova. When the ova reach maturity only a few inclusions are present in the alveoli. This is not the case in the spring cycle. Following fall spawning, gametogenesis starts after only a short period of inactivity. Mya appears to be unable to build up nutritive reserves (inclusions) prior to the initiation of the second cycle. Therefore, nourishment obtained from intake of food must be converted directly into development of gametes.

It is obvious that when temperature is low, feeding is limited and metabolic activity is greatly reduced, thus gametogenesis occurs at a very slow rate during the winter. Why the spring development was not completed during 1962 is not known, but this is probably not unusual since evidence (Pfitzenmeyer, 1957) shows that spring spawning in Maryland has not been successful in some past years.

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PONTELLID COPEPOD OCCURRENCE IN THE CENTRAL SOUTH PACIFIC

BY KENNETH SHERMAN

PONTELLID COPEPOD OCCURRENCE IN THE CENTRAL SOUTH PACIFIC

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ABSTRACT

The distribution of pontellid copepods collected in the central South Pacific from January to April 1962 was examined for associations with hydrographic features, particularly water temperature and salinity. Of the 15 species of adult forms collected, 5 were found in all but one case within 40 km of islands and are considered to be associated with neritic waters. These were *Labidocera acuta, L. bataviae, L. pavo, Pontella denticauda,* and *Pontellopsis macronyx.* Five other species, *Pontella princeps, P. tenuiremis, P. securifer, Pontellopsis armata,* and *P. regalis,* revealed no association with temperature or salinity within the range of values encountered for those properties, but occurred throughout the area surveyed. *Pontellina plumata* appeared to be affected by temperature changes, favoring waters warmer than 26.0C. Of the remaining four species, the numbers of *Labidocera acutifrons, L. detruncata,* and *Pontellopsis villosa,* were reduced where the salinity was less than 34.5‰, while *Pontella fera* was found to be numerous in waters with salinity lower than 34.5‰.

INTRODUCTION

Previous investigations have shown that pontellid copepods are more abundant at the surface than in deeper levels in waters of the central Pacific (Wilson 1942; Heinrich 1960; Sherman 1963). The possibility of using pontellids as indicators of surface water movements in the Hawaiian Islands region was suggested earlier (Sherman 1963). The present study is concerned with the relationships between pontellid distribution and surface water characteristics, particularly salinity and temperature, in the region extending south and west of the Hawaiian Islands to New Caledonia and Samoa.

The study is based on 60 surface plankton samples taken by personnel of the U.S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, during Cruise 55 of the Bureau's research vessel *Charles H. Gilbert,* January to April 1962 (Fig. 1A).

Little is known of pontellid distribution in the central Pacific. Heinrich (1960, p. 45) reported that the occurrence in large numbers of several pontellids was "limited by the influence of the salinity factor." The abundant occurrence of the species *Pontellopsis villosa, Labidocera acutifrons, Pontella tenuiremis,* and *Pontellina plumata* was limited to waters with salinities greater than 35‰. *Pontella fera* was found "almost exclusively" in an area of low salinity (less than 35‰). Heinrich's samples were collected from transects made along longitudes 172° E and 174° W, between latitudes 30° N and 41° S, from November 1957 to February 1958.

Additional pontellid occurrence data for the Pacific is provided in the plankton lists and taxonomic works of Dana (1853), Brady (1883), Giesbrecht (1892), Cleve (1901), Scott (1909), Farran (1936), Dakin and Colefax (1940), Wilson (1942, 1950), Sewell (1948), and Grice (1961).

METHODS

All tows were made at the surface using a 1-meter net with mesh openings of 0.66 mm in the body section and 0.31 mm in the cod end. An Atlas flowmeter suspended in the mouth opening of the net recorded the amount of water strained. The duration of tow was approximately 30 min.

All pontellids in the total or an aliquot of the sample were removed and sorted by species, and the number of each species per 1,000 m^3 of water strained was calculated. Temperature-salinity-plankton projections were constructed for each species using the technique of Bary (1959) to de-

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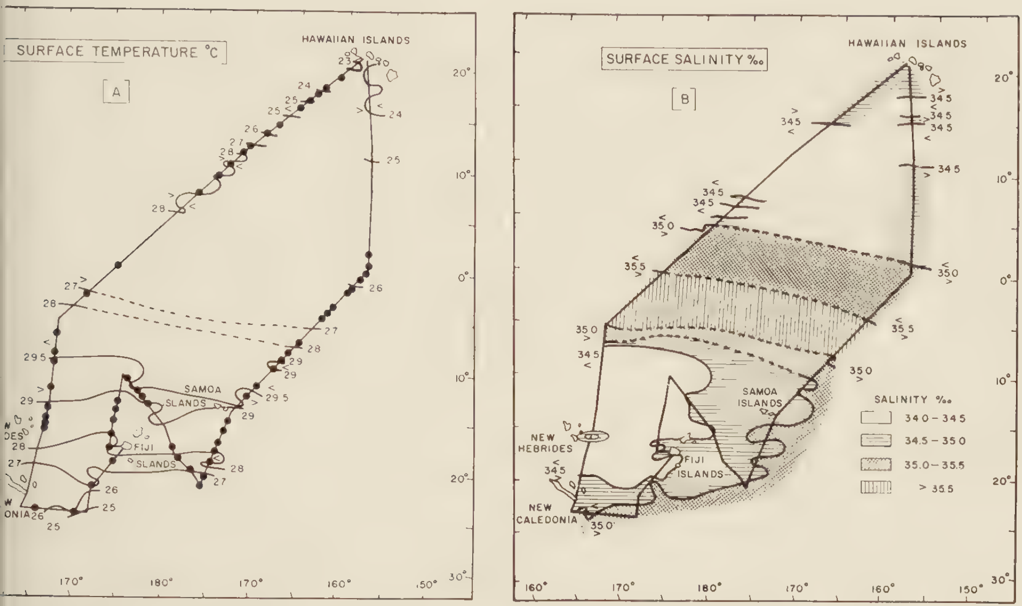

IG. 1. Vessel track, surface plankton station positions, and temperatures (A) and surface salinites
, *Charles H. Gilbert* Cruise 55, January–April 1962.

nine the relations between pontellids
surface hydrographic conditions. Iden-
ation of pontellids was facilitated by
rence to the taxonomic works of Gies-
cht (1892), Scott (1909), Sewell (1929),
Wilson (1950).

COMPOSITION OF SAMPLES

n the collections, there were 15 species
pontellids represented by adult forms
could be identified. These were
idocera acuta (Dana), *L. acutifrons*
ana), *L. bataviae* Scott, *L. detruncata*
ana), *L. pavo* Giesbrecht, *Pontella den-*
uda Scott, *P. fera* Dana, *P. princeps*
na, *P. securifer* Brady, *P. tenuiremis*
sbrecht, *Pontellopsis armata* (Gies-
cht), *P. macronyx* Scott, *P. regalis*
ana), *P. villosa* Brady, and *Pontellina*
mata (Dana).

wo groups of pontellids were found
could not be identified from published
onomic reports. One, a *Pontella* sp., ap-
red to be closely related to *P. tenuiremis*
P. fera; another, a *Pontellopsis* sp., was
ilar to published descriptions of female
macronyx.

There were immature representatives of the genera *Labidocera, Pontella,* and *Pontellopsis* for which it was not possible to make specific identification. These forms may have been single species or mixtures and were not used in attempts to relate distribution to water qualities.

RELATIVE ABUNDANCE

Relative abundance of pontellid copepods, expressed as percentage of total numbers present per 1,000 m^3 of water strained, varied among species. Immature forms of *Labidocera* sp. were the most abundant (38% of the total). Other categories of immature pontellids distinguished were *Pontella* sp. (3%) and *Pontellopsis* sp. (1%). Of the adult forms, *Labidocera detruncata* (24%), *L. acutifrons* (13%), *Pontellina plumata* (10%), and *Pontella fera* (4%) were most numerous. The adults of *Pontella tenuiremis, P. denticauda, Pontellopsis villosa, P. regalis,* and *P. armata* were less numerous (2–1% of the total). The remaining species, *Pontella securifer, P. princeps, Pontellopsis macronyx, Labidocera bataviae, L. pavo,* and *L. acuta,* were

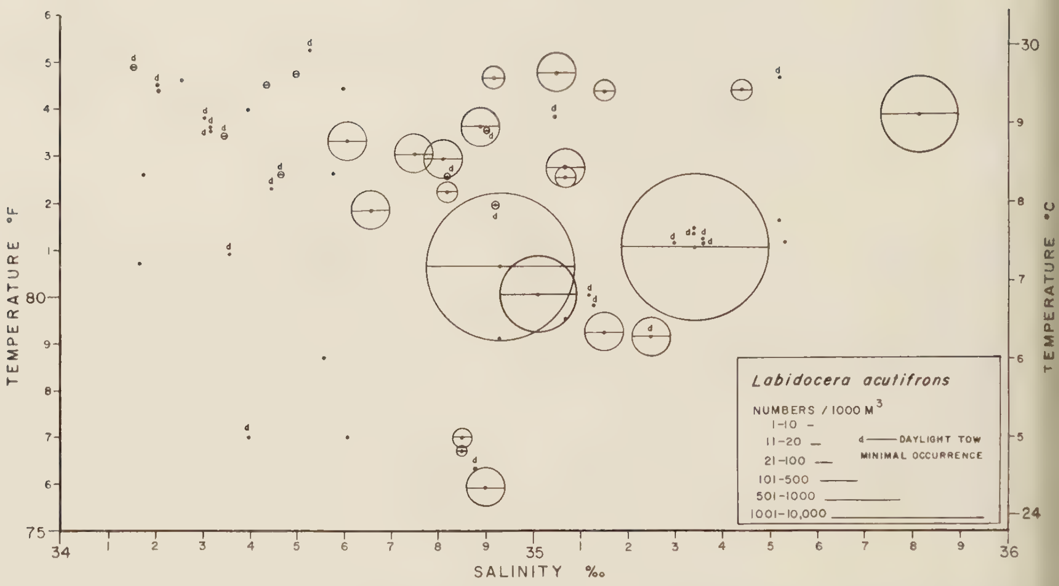

FIG. 2. Temperature-salinity-pontellid relation of *Labidocera acutifrons*. Symbols indicate ranges of pontellid abundance in numbers per 1,000 m^3 of water strained. Letter *d* represents tows taken during daylight hours, indicating minimal occurrence.

rare, each comprising less than 1% of the adults.

RELATION TO SURFACE TEMPERATURE AND SALINITY

Surface temperature and salinity distributions (Figs. 1A and B) were based on observations taken every 3 hr during the cruise. The temperature range was 5.7C, from 23.8C in the northern region to 29.5C in the vicinity of Samoa. Salinity ranged from 33.33‰ at the New Hebrides to 35.85‰ near 5° N lat, 162° W long.

Hydrographic data were inadequate to construct temperature-salinity curves for the surface waters from which my samples were collected. In the absence of accepted definitions of the surface water types in the area sampled, and in recognition of the clumped distribution[2] of pontellids, the temperature and salinity ranges within which the greatest numbers of each pontellid species occurred were estimated by inspection. Differences among the distributions of pontellids and surface salinity or temperature were thought to reflect environmental changes. However, the specific factor or group of factors limiting pontellid distribution has not been determined. For those species for which day-night differences in occurrence have been reported (Sherman 1963), a symbol has been used on the *T-S-P* projection to denote the time of expected minimal numbers.

The *T-S-P* relations of the four most numerous (> 4% of the total number present) species, *Labidocera acutifrons*, *L. detruncata*, *Pontellina plumata*, and *Pontella fera*, are shown in Figs. 2–5, respectively. Included for comparison is the less numerous *Pontellopsis villosa*, plotted with *Pontella fera* in Fig. 5.

Of the two variables measured, salinity appeared more important in limiting the distribution of *Labidocera acutifrons*. This species was found in aggregations of 100 per 1,000 m^3 or more over a wide temperature range (24.6–29.3C), with no apparent concentration at any temperature. In contrast, there was a sharp reduction in num-

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[2] This clumped distribution is evident in the occasional occurrence of low numbers of pontellids at stations located in areas of high pontellid concentration.

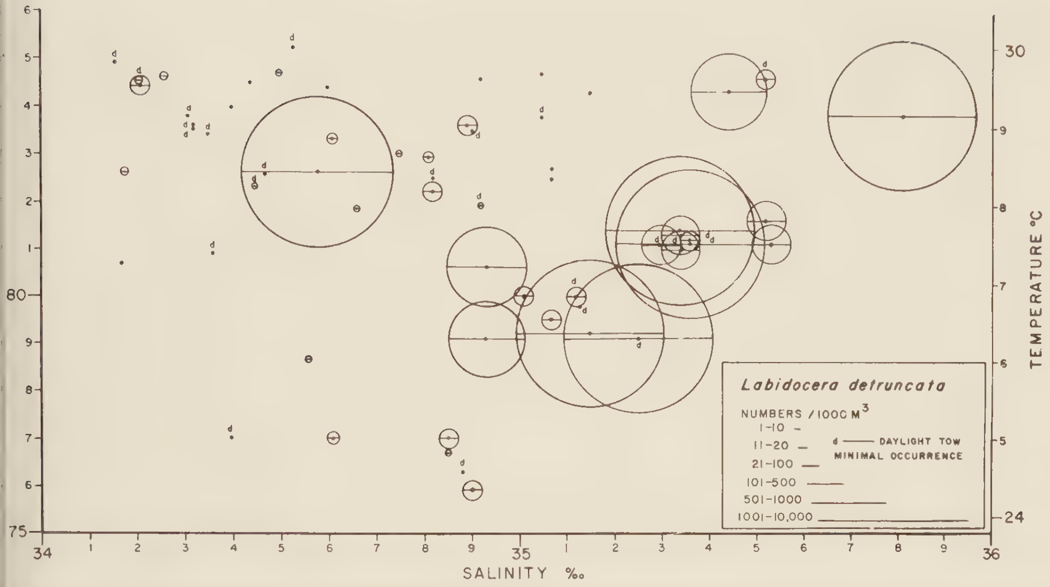


Fig. 3. Temperature-salinity-pontellid relation of *Labidocera detruncata.* Symbols as in Fig. 2. Let- r *d* represents tows taken during daylight hours, indicating minimal occurrence.

rs of *L. acutifrons* from stations where linity values were > 34.6‰ (100 to more an 1,000 per 1,000 m^3), to stations where linities were < 34.4‰ (10 or less per 000 m^3) (Fig. 2). In view of this sharp duction, the 34.5‰ isohaline was selected to distinguish between low- and high-salinity water. *L. detruncata* was also found in numbers greater than 1,000 per 1,000 m^3 in salinities > 34.5‰, but the reduction in numbers in waters of less than 34.5‰ salinity was less pronounced than

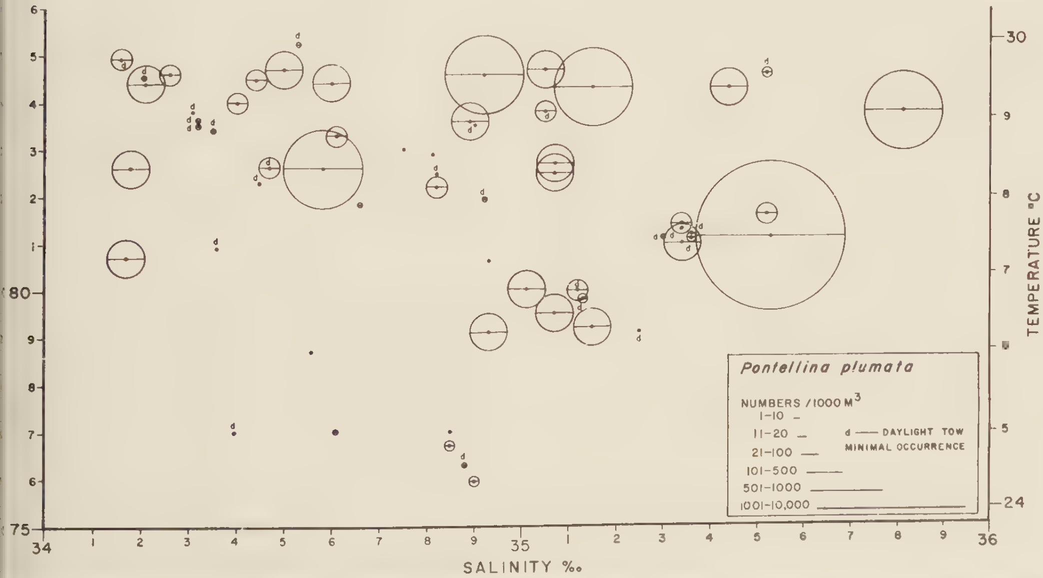


Fig. 4. Temperature-salinity-pontellid relation of *Pontellina plumata.* Symbols as in Fig. 2. Letter *d* presents tows taken during daylight hours, indicating minimal occurrence.

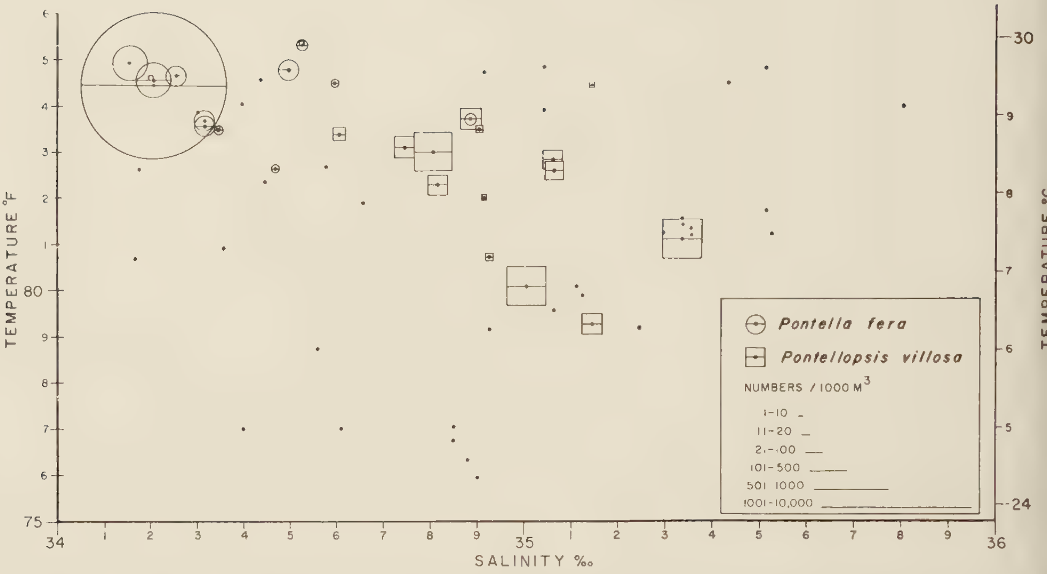


FIG. 5. Temperature-salinity-pontellid relation of *Pontella fera* and *Pontellopsis villosa*. Symbols as in Fig. 2.

for *L. acutifrons*. Generally, fewer than 20 per 1,000 m³ occurred at a station, except at one station in low-salinity water, at which 79 per 1,000 m³ were present (Fig. 3). In addition to salinity, temperatures cooler than 26.0C, where less than 100 per 1,000 m³ occurred, appeared to limit the distribution of *L. detruncata*.

Pontellina plumata occurred in concentrations exceeding 100 per 1,000 m³ throughout a wide range of salinity (34.1‰–35.8‰), with no abrupt reduction in low-salinity waters except for 10 or fewer per 1,000 m³ found at several stations located in salinities less than 34.4‰; however, these values were determined from samples collected during daylight and therefore represent minimal estimates of occurrence (Fig. 4). In relation to temperature, *P. plumata* was found to be less numerous (< 20 per 1,000 m³) in waters cooler than 26.0C.

Pontella fera was most numerous, up to 2,200 per 1,000 m³, in low-salinity, warm (> 28.5C) waters. Its occurrence in high-salinity water (>34.5‰) was limited to three stations where less than 18 per 1,000 m³ were found. In contrast, *Pontellopsis villosa* was more numerous (up to 160 per 1,000 m³) in higher salinity (> 34.5‰) cooler (< 28.5C) waters (Fig. 5).

The contrasting occurrence in relation t temperature and salinity of *Pontella fer* and *Pontellopsis villosa* suggests that thes species are associated with two distinc surface waters of different origin and tha the two waters mixed to a degree, as evidenced by the low numbers (< 18 pe 1,000 m³) of *P. villosa* found at severa stations in low-salinity water and of *Pontella fera* in high-salinity water. The absence of large numbers of *Labidocer acutifrons* and *L. detruncata* in low-salinit waters also suggests that these waters ar distinct in origin.

The less abundant species (< 4% of th total), *Pontella tenuiremis*, *P. securifer*, *P princeps*, *Pontellopsis armata*, and *P. regalis* were all widely distributed. The remainin rarely occurring pontellids (< 1% of th total), *Pontella denticauda*, *Pontellopsi macronyx*, *Labidocera acuta*, *L. bataviae* and *L. pavo*, were found at only a few stations and were in insufficient numbers fo reliable *T-S-P* estimates. However, all c them were collected within approximatel 40 km of islands, except two *Pontellopsi*

TABLE 1. *Station number, distance from nearest land, and approximate depth of locations at which* Pontella denticauda, Pontellopsis macronyx, Labidocera acuta, Labidocera bataviae, *and* Labidocera pavo *were collected**

Station	Species	Approximate distance from nearest island (km)	Approximate depth over which collections were made (m)
30	*Labidocera pavo*	25 (Mitre Island, New Hebrides)	2,700–4,500
35	*Pontella denticauda*	30 (Ambrim Island, New Hebrides)	2,700
	Labidocera acuta		
	Labidocera bataviae		
36	*Pontella denticauda*	10 (Epi Island, New Hebrides)	900
	Pontellopsis macronyx		
	Labidocera acuta		
	Labidocera bataviae		
53	*Pontella denticauda*	40 (Kandavu Island, Fiji)	2,700
74	*Labidocera pavo*	28 (Rotuma, Fiji)	2,700–4,500
85	*Pontella denticauda*	25 (Lau Group, Fiji)	2,700
	Labidocera pavo		
86	*Pontella denticauda*	20 (Tongatabu Group, Tonga)	1,800
89	*Labidocera pavo*	20 (Eua Island, Tonga)	2,700
	Pontellopsis macronyx		
99	*Pontellopsis macronyx*	75 (Tutuila Island, Samoa)	4,500–6,400
102	*Labidocera bataviae*	10 (Tutuila Island, Samoa)	2,700

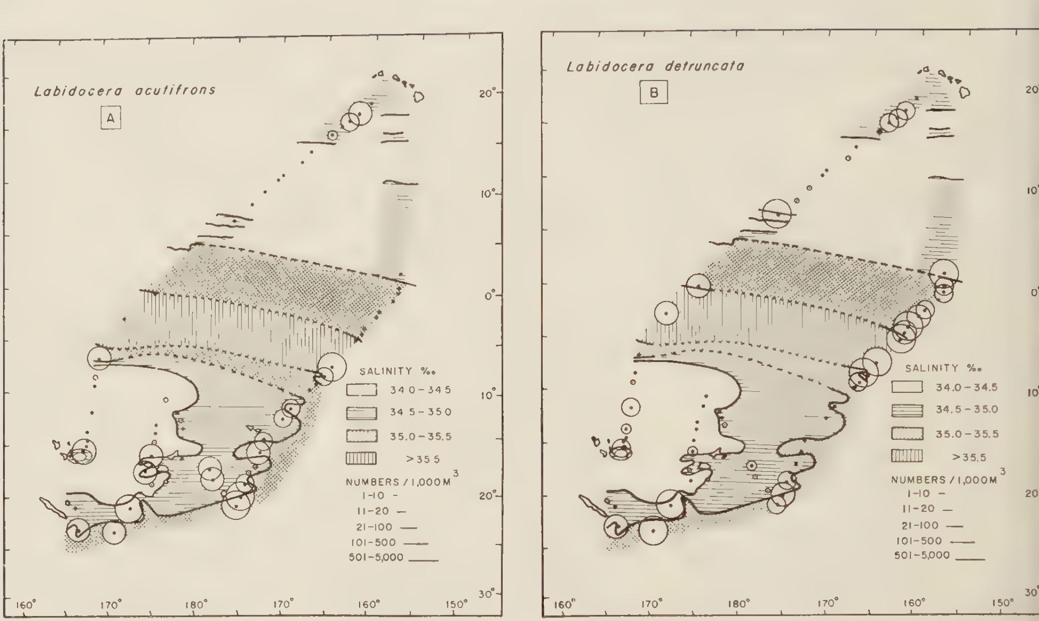
* Bathymetry data from U.S. Navy Hydrographic Office Chart, H. O. Misc. 15, 254, 2nd ed., October 1961.

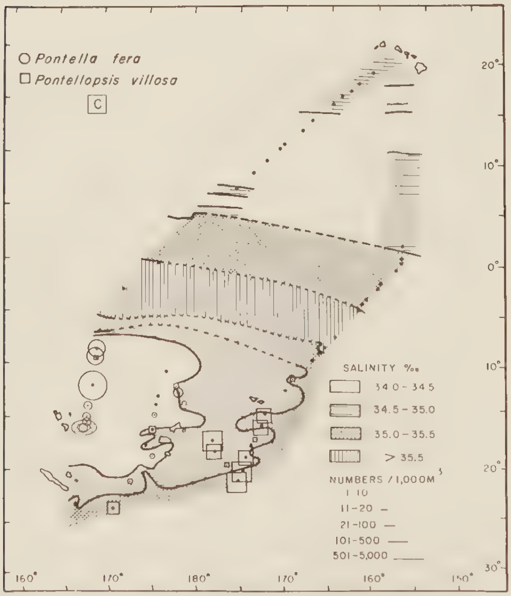
macronyx found at Station 99, 75 km from the nearest land area (Table 1). It appears that these species are more closely related to island influences than to temperature and salinity values. This apparent island association is in agreement with the findings of Sewell (1948, p. 323–324), who included *Pontella denticauda, Pontellopsis macronyx, Labidocera acuta, L. bataviae,* and *L. pavo* in a listing of Indian Ocean calanoids classified as "essentially littoral in character." In addition, Scott (1909) reported all of these species but *L. pavo* from the Malay Archipelago, including the type specimens of *Pontella denticauda, Pontellopsis macronyx,* and *Labidocera bataviae.*

DISCUSSION

The distributions in relation to surface salinity of *Labidocera acutifrons, L. detruncata, Pontellopsis villosa,* and *Pontella fera* (Fig. 6A–C) show a break in the distribution of these species near (within approximately 10 km of) the 34.5‰ isohaline (north and west of New Caledonia and Fiji), where there was a decrease in numbers of *Labidocera acutifrons, L. detruncata,* and *Pontellopsis villosa.* North of the equator, the break at the 34.5‰ isohaline was more pronounced for those species present, with *Labidocera acutifrons* absent from waters of less than 34.5‰ salinity and *L. detruncata* reduced from 100 per 1,000 m^3 at several locations in high-salinity water (> 34.5‰) to 10 per 1,000 m^3 or less in low-salinity water.

Near the Hawaiian Islands, salinities of 34.5‰ have been reported to represent the northern boundary region of the North Pacific Equatorial Water type (Sherman 1963). Several pontellids, including *L. acutifrons* and *L. detruncata,* decreased markedly from a region of abundance to the north in the high-salinity (> 34.9‰) North Pacific Central Water type to absence of the former species and to low numbers of the latter near the 34.5‰ isohaline. Although *Pontellopsis villosa* was not found in the central North Pacific, Heinrich (1960) reported it present in waters with salinities greater than 35.0‰ from latitudes 30° N to 20° N and 10° S to 30° S along longitudes 174° W and 172° E, and absent from waters with salinities lower than 35.0‰ between latitudes 20° N to 10° S. This association of *P. villosa* with high-salinity water generally agrees with the present findings; however, in our material





the lower limit of *P. villosa* abundance was at 34.5‰. The smaller numbers of the forms associated with high-salinity, *Labidocera acutifrons, L. detruncata,* and *Pontellopsis villosa,* and of the form associated with low-salinity, *Pontella fera,* in waters of 34.5‰ salinity, suggest that this isohaline is a faunal and a hydrographic boundary.

FIG. 6. Horizontal distribution of (A) *Labido cera acutifrons,* (B) *Labidocera detruncata,* an (C) *Pontella fera* and *Pontellopsis villosa,* in re lation to surface salinity, *Charles H. Gilbert* Cruis 55, January–April 1962. Symbols as in Fig. 2.

On the other hand, in a recent study c surface plankton of the Indian Ocea Voronina (1962) found that the distribu tions of *Pontellopsis villosa, Pontella fer Labidocera detruncata,* and other ponte lids were more closely related to curre systems than to specific salinity or tempera ture values. However, it is difficult to con pare the distributions found by Voronir with the present ones, because Voronir used the percentage composition of th total numbers of pontellids in surface traw collections in which the amount of wate strained could not be determined.

Rochford (1959, p. 19, Pl. 2) has ind cated the presence of a hydrograph boundary in the region of New Caledon and Fiji, characterized by the mixing relatively low-salinity (34.69‰) surfac waters of the South Equatorial Water ma with surface waters of the higher-salinit (36.53‰) West Central South Pacific W ter mass during the month (Decembe closest to our sampling. The break in po tellid distribution found in association with the 34.5‰ isohaline in the present study was also located in this same region (latitude 10° to 20° S, longitude 175° E to 175° W). Rochford's report represents hydrographic conditions during 1955–1956, making comparisons questionable. Nevertheless, it provides a basis for discussing the possible relation between pontellids and surface water movement.

Pontella fera was the only pontellid abundant in waters with salinities below 34.5‰. This water was in the southwestern region of the survey area, adjacent to New Caledonia and the New Hebrides Islands (Fig. 6C). Rochford's description of surface water movement in this region in December indicates that the relatively low-salinity (34.69‰) South Equatorial surface water moves southwest from its region of origin (100% composition), between longitudes 160° E and 180°, latitudes 5° to 10° S, into the higher-salinity (36.53‰) West Central South Pacific surface water in the immediate vicinity of New Caledonia and Fiji. During the months of sampling, January and February, the flow pattern in this region changes substantially from a generally easterly direction from April to December to southerly during the January–March period under the influence of the monsoons, with the equatorial water masses entering the region of New Caledonia from the north and northeast (Wyrtki 1960, p. 30).

This seasonal shifting of the current pattern could explain the low-salinity water in the vicinity of New Caledonia in January and February. Surface waters less saline than 34.69‰, originating from the region of low salinity (Schott 1935, Fig. 27) and high precipitation (Jacobs 1951, Fig. 34) north and west of New Caledonia, could be expected to be transported southward during January and February. The increasing numbers of *P. fera* found with decreasing salinities in this region suggest that waters less saline than 34.5‰ represent the low-salinity South Equatorial surface waters moving into the region from the north and northeast. In contrast, the higher-salinity West Central South Pacific surface waters flow westward from a salinity maximum region (> 35.0‰) into the lower-salinity South Equatorial surface waters, with considerable mixing (50% of each) of these distinct waters occurring in the vicinity of New Caledonia and Fiji during the winter months (Rochford 1959, Pl. 3, 4). The increase of numbers of *Labidocera acutifrons*, *L. detruncata*, and *Pontellopsis villosa* westward, with increasing salinity, suggests that they are closely associated with the West Central South Pacific surface waters.

The five island-associated pontellids occurred within the southern subtropical gyre formed by the South Equatorial Current, west wind drift, and eastern and western boundary currents (Reid 1962). A number of major islands and archipelagos of the Pacific are also located within and adjacent (Malay Archipelago) to this gyral system, including the Marquesas Islands, where Jones (1962) found neritic copepods at distances up to 65 km from land. He ascribed the relatively high offshore plankton volumes to the enriching effect of nutrients carried offshore by currents. The presence of neritic copepods in offshore waters was considered by Jones as supporting evidence of the presence of nutrients of land origin. The occurrence of neritic or littoral copepods in offshore waters could, assuming that Jones is correct, indicate the presence of island-associated water that might be undetected during standard oceanographic observations.

Five species, *Pontella princeps*, *P. securifer*, *P. tenuiremis*, *Pontellopsis regalis*, and *P. armata*, were found distributed over a wide area, in low numbers, and with no apparent relation to either surface salinity or temperature values within the survey region. *Pontellina plumata* was found over a wide area, with greatest numbers located in waters warmer than 26.0C. Three additional species appeared to be affected by temperature change: *Pontella fera*, favoring waters warmer than 28.5C, *Pontellopsis villosa*, favoring waters cooler than that temperature, and *Labidocera detruncata*, found in decreasing numbers in water cooler than 26.0C.

The differences among the distributions of several pontellid copepods in the central South Pacific show that this group contains a number of species that reflect environmental changes. The specific limiting factor or group of factors has not been determined. However, the close relation to salinity values of *Pontella fera* (low), and of *Labidocera acutifrons, L. detruncata,* and *Pontellopsis villosa* (high) and to island-associated waters of *Pontella denticauda, Pontellopsis macronyx, Labidocera acuta, L. bataviae,* and *L. pavo* attests to the utility of these organisms as biological indicators of low-salinity South Equatorial surface water, high-salinity West Central South Pacific surface water, and island-associated water, respectively.

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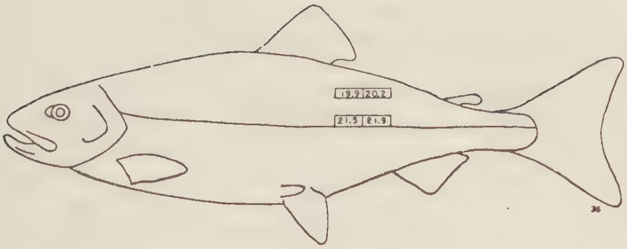

FIGURE 35. Arithmetic mean values of the number of circuli from the focus to the annulus on "A" zone scales from above the lateral line and scales from the body area sampled on high seas fish.

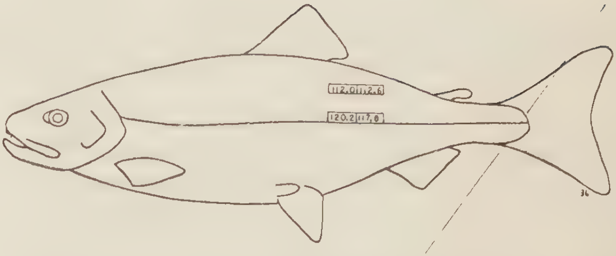

FIGURE 36. Arithmetic mean vaues of the length from the center of the focus to the thirtieth circulus on "A" zone scales from above the lateral line and scales from the body area sampled on high seas fish.

Scale characters in Table 29 follow a pattern similar to the length from the center of the focus to the thirtieth circulus (Figure 36).

These analyses show that a greater degree of uniformity in pink salmon scale sampling procedures among agencies of the International North Pacific Fisheries Commission will be necessary for our future studies.

SUMMARY AND CONCLUSIONS

Pink salmon collected in 1957, 1958 and 1960 were examined with the classification criteria based upon the 1959 data. The results of this study indicated that the discriminant function computed from the 1959 data was not suitable for the salmon collected in other years.

The use of scale characters alone to classify pink salmon taken on the high seas was studied. The scale characters were found to correctly assign 79.9 per cent of the individual fish in the 1959 eastern Kamchatkan and western Alaskan samples to their continental type. The addition of two characters obtained from radiographs of ossified structures raised the value to 85.7 per cent. The results of this study indicated that scale characters alone might classify fish taken on the high seas with a high probability of correct classification.

Several methods of increasing the size of pink salmon scale samples were examined. As a result of these studies, the number of poor plastic scale impressions, regenerated scales and absorbed scales was lessened. Selection of scale samples from that part of the "A" zone above the lateral line has increased the utility of the samples, but still greater uniformity in sampling procedures is needed. Precise results from future research will depend on the selection of scales from a specific body area.

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BERING SEA KING CRAB INVESTIGATIONS

by Herbert Shippen

King crab research at the Seattle Biological Laboratory will be terminated July 1964. In preparation are reports on yield per recruit, growth of juvenile and adult male crabs, movement of tagged crabs, and distribution as determined on the basis of otter trawl surveys in 1957–1961. Tags recovered from more than 1,200 male crabs released in the years 1955 through 1961 have been received from Japanese fishing operations in the eastern Bering Sea during 1962; none from the 1962 Soviet fishery has yet been returned. Reported here are average annual rates of exploitation and survival during 1957 and 1958, and a preliminary experiment to assess the retention of tags.

AVERAGE ANNUAL RATES OF EXPLOITATION AND SURVIVAL, 1957 AND 1958

The survival rate of adult male king crabs in the eastern Bering Sea has been investigated by analyzing the return of tagged crabs released and recaptured over a period of several years. Because of a number of factors such as gear selectivity and placement as well as molting frequency, a greater portion of larger

International North Pacific Fisheries Commission, Annual Report 1963, Vancouver, Canada, p. 165-167, 1964.

TABLE 30. Average rate of exploitation during 1957 and 1958 of male king crabs in each five millimeter length class.

Carapace length (mm.)	Rate of exploitation (%)	Weighting factor (100/rate of exploitation)
135	1.84	54.3
140	2.74	36.5
145	4.33	23.1
150	5.93	16.9
155	7.23	13.8
160	9.34	10.7
165	10.73	9.3
170	11.76	8.5
175	12.29	8.1
180	12.81	7.8
185	13.33	7.5

than smaller crabs in the stock is captured by the fishery. For this reason it is convenient in the analysis of king crab tag recoveries to utilize a relative weight for each size-class at time of recovery. The weight should reflect the percentage of the total abundance of each size-class removed by the fishery.

In approaching the problem of the effect of fishing upon the stock of eastern Bering Sea king crabs, one of our fundamental assumptions is that the period of fishing, May through October, is a time during which there is relatively little natural mortality. Molting, which occurs in late winter or early spring in commercial-sized crabs, is presumably the major source of natural mortality. Thus it is both convenient and realistic to view the year as being divided into two periods, a " summer " period of fishing without natural mortality in the adult male population, followed by a " winter " or molting period during which there is no fishery but which includes all the natural mortality and recruitment.

In 1957 and 1958 the Seattle Biological Laboratory conducted extensive otter trawl surveys in the eastern Bering Sea. These surveys were designed to cover the entire distribution of adult male crabs, and they provide abundance data which we have used to estimate the total number of each size-class prior to fishing. Catch statistics furnished by the Japanese Fisheries Agency from the factoryship *Tokei Maru*, which in 1957 and 1958 took 92 and 100 per cent, respectively, of the total crabs taken in the area, give an estimate of the size composition of the commercial catch. Under the assumption that there is no recruitment or natural mortality during the period of fishing, the fraction of abundance prior to fishing which is removed by the fishery may be designated the rate of exploitation. Table 30 shows the estimated rate of exploitation by size-class. The rates shown are averages for 1957 and 1958 since differences between years are likely less than are errors of estimation.

If it be assumed that the average rate of exploitation for each size-class remains relatively constant over the period from 1956 through 1960, the reciprocal of the rate may be used to derive the weighting assigned to tag returns in the analysis of survival rates. For example, the rate of exploitation for 150 mm. crabs (148–152 mm.) is 0.0593. Each tagged crab returned at this size represents 1/0.0593 or 16.86 survivors of the original release lot. Certain restrictions have been observed in applying the methods described above.

1. Our objective is to estimate the survival of male crabs 133 mm. and greater in carapace length at time of release.

2. Only crabs released with the spaghetti (arthral muscle) tag during the period from 1955 through 1958 are included.

3. Only tagged crabs recovered by the *Tokei Maru* from 1956 through 1960 are included. All recoveries are assumed to have been returned.

4. Tag releases are lumped by year of release, and returns are considered by year of recapture.

On the basis of tag returns and weighting factors the number of survivors of each release group has been calculated. Logarithms of these estimates are shown in Figure 37. Rate of survival is indicated by the slope of the line connecting logarithms of successive survival estimates—the greater the slope, the lesser the survival. There is evidently little, if any, change in the survival rate of the various release groups with time, nor does there appear to be much difference between release groups. Therefore, an average for all ten observed survival rates has been calculated at 0.5056.

In view of the increasing rate of exploitation with size apparent in Table 30 and the relatively constant survival rate, it follows that the combined effects of factors other than fishing which influence survival of tagged crabs tend to decrease with size and age. Most important of these other factors are probably natural mortality and rate of tag loss. Neither has been adequately studied under natural conditions, and future research efforts on king crab stocks should most certainly include them. An experiment to assess one aspect of tag retention was conducted by the Seattle Biological Laboratory and is described below.

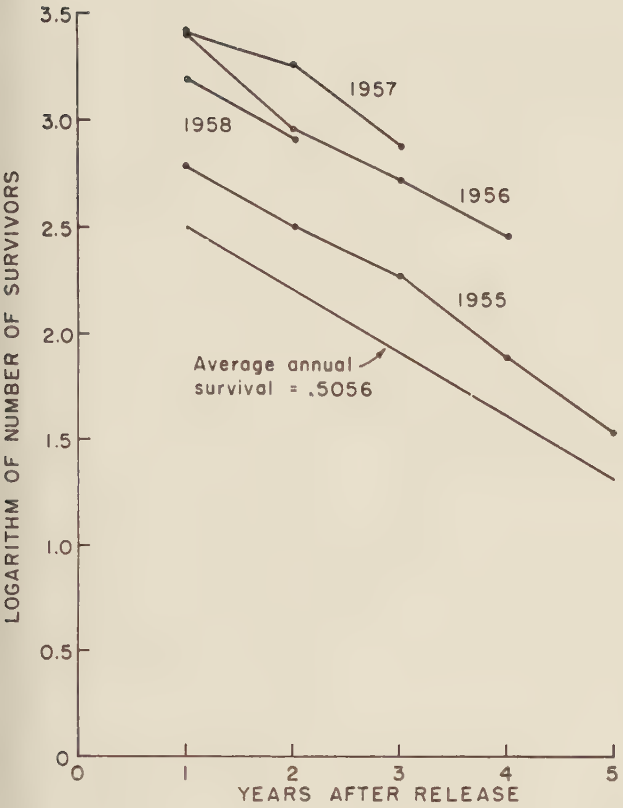

FIGURE 37. Survival of adult male king crabs larger than 132.5 mm. carapace length released 1955 through 1961 and recovered 1956 through 1960.

DOUBLE TAGGING EXPERIMENT TO ASSESS TAG RETENTION

United States investigators in the eastern Bering Sea released a number of double-tagged adult male king crabs during the summer of 1961. These crabs had a spaghetti type tag through the posterior border of the carapace in addition to the usual tag through the arthral muscle at the junction between carapace and abdomen. The objective of this experiment is to assess the retention of the arthral tag from the time of release until the time of molting. The number of such releases was limited, unfortunately, by curtailment of the vessel charter period; conclusions from the experiment can at best be regarded as provisional. However, the results that have been obtained are of interest since tag loss has a direct effect on estimates of survival and mortality that are based upon tag returns.

TABLE 31. Returns from 350 double-tagged adult male king crabs released in the eastern Bering Sea in July 1961.

Recovery season	Both tags returned	Only arthral tag returned	Only carapace tag returned	Total crabs returned
1961	12	0	0	12
Spring-summer 1962	19	0	4	23
Autumn 1962	13	2	1	16
Totals	44	2	5	51

Japanese and Soviet fishermen have returned tags from a total of 51 of the double-tagged crabs released in 1961 (Table 31). In the two instances where only the arthral tag was returned it may be assumed that the carapace tag was lost because of molting. Thus, there are five cases out of a total of 49 where the arthral tag was not returned together with the carapace tag. If we assume that all recovered tags were returned, then there appears to have been an annual loss of the arthral tags of 5/49, or approximately 10 per cent, by the non-molting crabs. Large-scale repetition of this experiment would be desirable.

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Effectiveness of Tilapia as Live Bait for Skipjack Tuna Fishing

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ABSTRACT

In Hawaii, *Tilapia mossambica* is reared as live bait to supplement the chronically short supply of the native bait fish, the nehu (*Stolephorus purpureus*). Effectiveness of tilapia and nehu as bait for skipjack tuna (*Euthynnus pelamis*) was compared in the course of fishing experiments carried out in 1962 in Hawaiian waters. For all sizes of skipjack, slightly more schools responded positively to nehu than to tilapia. Nehu produced higher catch rates (fish caught per minute), and this superiority was more pronounced with large skipjack than with small ones. Since the shortage of bait fish for the Hawaiian skipjack fishery remains critical, further work should be done to develop techniques for using tilapia as bait and to determine whether the availability and hardiness of tilapia can compensate for their inferior effectiveness as bait.

INTRODUCTION

The development of surface tuna fisheries the central and western tropical Pacific s been held back in part by lack of an ade- ate supply of live bait. The bait fish prob- n is critical in the skipjack tuna (*Euthyn- s pelamis*) fishery of Hawaii. Suitable bitat for the native bait fish, the nehu *tolephorus purpureus*), is limited, avail- ility fluctuates widely, and the species is torious for poor survival in the bait wells. waiian fishermen spend on the average ly 15 days a month in scouting and fishing skipjack (King and Wilson, 1957). A ge part of the remaining time is required locating and catching bait fish. The eco- mic loss occasioned by the time spent in ching bait fish is aggravated by the sharply sonal character of the fishery, 77 percent of annual skipjack landings, on the average, ing made in the 5-month period from May ough September (Yamashita, 1958). It is dent that a ready, adequate supply of bait ring this period would go far toward help- the Hawaiian pole-and-line skipjack fish- fleet to realize its maximum potential pro- ction.

Various attempts have been made to allevi- the bait shortage. Brock and Takata 955)[1] recommended several measures, including mechanical aeration of the bait wells in order to reduce mortality. This recommendation, however, has never been adopted by the fishermen. Other proposed solutions to the bait problem have included the adoption of fishing techniques which do not rely upon live bait and the supplementing of the natural bait supply by introduction of suitable species. Attempts to catch skipjack in commercial quantities using purse seines (Murphy and Niska, 1953) and gill nets (Matsumoto, 1952; Shomura, 1963) have been unsuccessful in Hawaii. Several species have been introduced to Hawaiian waters in the hope that they might prove useful as tuna bait fish. The first such introduction was that of tilapia (*Tilapia mossambica*) (Brock and Takata, 1955). Subsequently, the Marquesan sardine (*Harengula vittata*) was planted in Hawaiian coastal waters (Murphy, 1960) and the threadfin shad (*Dorosoma petenense*) in several streams and reservoirs (Hida and Thompson, 1962). The sardine has not become available in sufficient numbers to be of significance to the skipjack fishery. The threadfin shad has become established, but its effectiveness as skipjack bait has not yet been tested. This species has reproduced successfully in the streams and reservoirs.

The present paper compares the results obtained with nehu and tilapia in experimental pole-and-line fishing that was done incidentally to an experiment in gill-net fishing for skipjack tuna (Shomura, 1963). Since the emphasis was on the gill-net experiments, data on the pole-and-line fishing phase are few, but they are presented here because little information on the performance of tilapia as a bait fish has been published (Brock and Takata, 1955; King and Wilson, 1957).

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[1] Brock, Vernon E., and Michio Takata. (1955) ntribution to the problems of bait fish capture mortality together with experiments in the use of tilapia as live bait. Territory of Hawaii, Industrial Research Advisory Council Grant No. 49, Final Report. 39 pp.

METHODS AND MATERIALS

From May to August 1962 a number of fishing experiments were carried out aboard the chartered skipjack sampan *Broadbill* in the area of the Hawaiian skipjack fishery. Live nehu were used as chum bait during the first portion of the field work. In July a change was made to tilapia because of the low availability of nehu on the baiting grounds. The tilapia were purchased from a tilapia hatchery set up by the state of Hawaii on a pilot-plant scale to produce bait for the skipjack fishery.

In the field work, detailed records were kept of each bird flock and fish school sighted and the results of fishing, *e.g.*, time of sighting, time chumming was started, species composition of the school, size of fish, amount of fishing effort, and catch. The principal shortcoming of the data is that pole-and-line fishing was not carried to completion on any of the schools, *i.e.*, the maximum possible catch was not realized. In most instances pole-and-line fishing was terminated at the peak of activity in order to set the gill net.

RESULTS

In the Hawaiian skipjack fishery, actively feeding bird flocks are utilized as the principal means of locating fish schools. One of the hypotheses advanced to explain the association is that the sea birds feed on small fish and squid driven to the surface by predatory schooling fishes. A necessary assumption in the present discussion is that in every case where an actively feeding bird flock was approached and bait was chummed there was a skipjack school present, even though fish were not caught or even seen.

TABLE 1.—*Comparison of effectiveness of nehu a*
tilapia in inducing skipjack schools to bite

	Nehu	Tilap
Total number of schools chummed	74	73
Number of schools abandoned as too small or wrong species	12	21
Number of schools fished without any catch	29	30
Number of schools from which one or more fish were caught	33	22

The size of bait fish and size-associated differences in their behavior may be critic
factors affecting the response of skipjack
them. King and Wilson (1957) observed th
tilapia larger than about 75 mm tended
sound when used as chum, while small
tilapia tended to stay near the surface ar
swim along with the boat. Tilapia and neh
used in the present study were of generally th
same size. The average standard length
tilapia from a sample of 100 fish was 29 mr
while the average size of a similar sample
nehu was 34 mm.

For convenience in discussion the skipja
schools have been classified as small skipja
(less than 3.6 kg), medium skipjack (4.1
6.8 kg), and large skipjack (more than 6
kg).

A summary of the schools chummed wi
nehu and tilapia and the results of fishing
given in Table 1. Fishing efforts were halt
after the initial chumming and before any fi
were taken from 12 schools chummed wi
nehu and 21 schools chummed with tilapi
because the fish were judged to be either ve
small skipjack (less than 1.8 kg) or speci
other than skipjack, *e.g.*, dolphin (*Coryphae*
hippurus) or yellowfin tuna (*Thunnus alb*
cares).

Of the schools on which chumming was co
tinued until a definite response or lack
response could be determined, 33 out of
(53 percent) of those chummed with ne
yielded catches of one or more skipjack. Th
minimum criterion of response was met
22 out of 52 (42 percent) of the scho
chummed with tilapia. By way of compariso
Royce and Otsu (1955), studying the resu
of fishing from a research vessel in Hawaii
waters, reported that 43 percent of the sk
jack schools chummed responded to neh
Yuen (1959), analyzing data from comm
cial fishing in the same area, found that
percent of the schools chummed with ne
yielded catches.

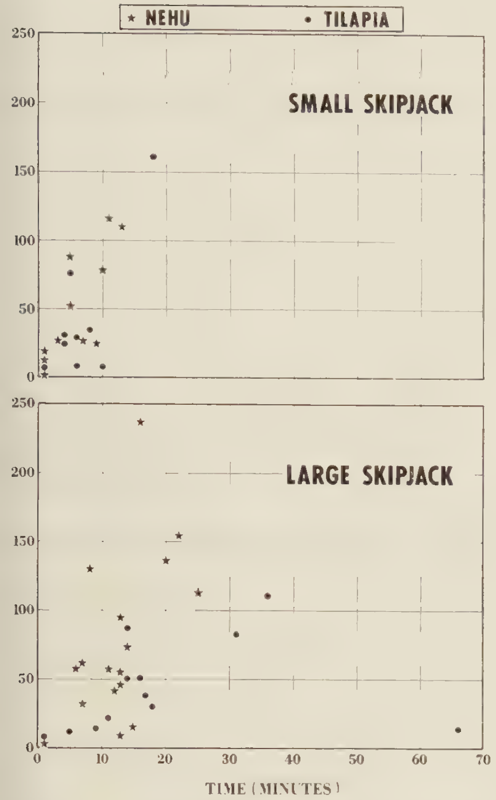

FIGURE 1.—A comparison of catch rates obtained
th nehu and tilapia on small and large skipjack.

In some cases it was possible by visual ob-
rvation to ascertain the approximate size
the skipjack even in the schools from which
fish were captured. Data pertinent to the
ation of response to fish size and kind of
it are presented in Tables 2 and 3. Al-
ough the sample is small, it appears that
ere is no direct relationship between size
skipjack and response to either bait.

Figure 1 shows the catch and the duration
fishing for a number of schools of small
d large skipjack. For small skipjack, the
erage catch rate with nehu as the bait fish
s 8.4 fish per minute, while with tilapia
catch rate was 6.2 fish per minute. The
ference in catch rates was more pronounced
th large skipjack. The average catch rate
th nehu of 6.1 fish per minute was consider-
ly higher than the 2.9 fish per minute taken
th tilapia. The distribution of the catch
es for individual schools (Figure 1) shows
it the higher average catch rate for large skipjack was not due to a few exceptionally good catches but to the consistently superior effectiveness of nehu.

TABLE 2.—*Numbers of completely unresponsive schools, by size of component skipjack and kind of bait used*

School composition	Nehu	Tilapia
Small skipjack	3	3
Medium skipjack	2	2
Large skipjack	1	3
Unidentified fish	23	22
Total	29	30

DISCUSSION AND SUMMARY

On the basis of the present data, tilapia does not appear to be as effective a bait fish as nehu for pole-and-line fishing of skipjack. While the ability to produce a catch of at least one fish from a school is nearly the same for the two bait species, the catch rate of large skipjack with nehu was twice that obtained with tilapia. These preliminary results should, however, be viewed with caution. Yuen (1959) examined commercial fishing operations in which nehu was used as the bait fish and found that skipjack response in pole-and-line fishing varied considerably, *e.g.*, the duration of fishing for 86 skipjack schools ranged from 1 to 82 minutes. Moreover, the catch rate (number of skipjack/hook-minute) differed considerably from school to school and with time for the same school.

In this comparison of the two species of bait fish, several conditions unfavorable to tilapia should be taken into account. While the development of nehu as a successful bait fish has been carried out over many years, tilapia is new to Hawaiian fishermen. There has not yet been time enough to determine the best procedures for fishing with tilapia, *e.g.*, size of bait, chumming rate, vessel speed, and type of hook. For example, at present the fishermen use a bright, shiny lure, which is comparable in reflection and color to the

TABLE 3.—*Numbers of responsive schools, by size of component skipjack and kind of bait used*

	Nehu	Tilapia
Small skipjack	14	9
Medium skipjack	2	0
Large skipjack	17	13
Total	33	22

nehu but presents a considerable contrast to the darker tilapia. Conceivably an increase in catch could be attained by employing a dull-colored lure when tilapia is used as the bait fish.

If tilapia is considered as a supplement to nehu rather than a substitute, several advantages become apparent in spite of the difference in effectiveness indicated by this study. Because tilapia is considerably hardier than nehu, it might be used to advantage during periods when skipjack schools are scarce in the usual fishing grounds. At such times, when the boats must range farther and scout longer to find fish, the use of nehu is inefficient, because the high mortality of nehu in the bait wells necessitates replenishing the bait supply after 3 to 5 days of scouting. Tilapia, on the other hand, can be carried in the bait wells with only negligible losses for 2 to 3 weeks or longer. This ability to carry tilapia for long periods would maximize scouting time and thereby increase the probability of locating the skipjack schools.

A second situation where tilapia could serve well as a supplementary bait is during periods of low availability of the nehu, especially when these occur during the skipjack fishing season. When fishermen have to spend 2 to 3 days in locating an adequate supply of bait fish for only 1 day of fishing, they would definitely benefit by using tilapia.

In conclusion, nehu appears to be a more effective bait fish for skipjack tuna than tilapia; however, in view of the shortcomings of nehu, *e.g.*, fluctuating availability and low viability, further studies should be made to develop tilapia up to its maximum efficiency as a supplementary bait fish. There is also a need for a more thorough evaluation of the comparative advantage to the fishermen of spending their working time in fishing skipjack with the readily available and more durable though somewhat less effective tilapia rather than in the more time-consuming and frequent baiting made necessary by the use of nehu.

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IMMUNOGENTIC AND BIOCHEMICAL APPROACHES TO THE IDENTIFICATION OF MARINE SUBPOPULATIONS

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ABSTRACT

The recognition of genetically self-sustaining fractions of marine species is of basic importance to most ecological or other biological studies. The genetic basis of so-called "physiological races," the extent of gene flow among subpopulations, the causes of short and long term variations in subpopulation boundaries, the genetic determinants of population resistance to such environmental factors as disease—all are related problems of significance. Within the past decade increasing use has been made of immunological and biochemical methods to understand the subpopulation structure of marine species. Information so obtained may augment that gained from morphological and physiological studies, or it may provide new insights not found with traditional approaches.

Probably the most definitive studies to date have employed blood typing techniques to determine blood group frequencies in marine vertebrates. Reproductively ioslated subpopulations of albacore and skipjack tuna have been recognized by significant variations in such frequencies. Whales from most of the world's oceans have been examined for frequencies of several blood factors, and subpopulation boundaries described. Blood group frequencies have indicated the existence of two coastal subpopulations of Atlantic herring in the Gulf of Maine, and of three reproductively isolated groups of Pacific sardines off California and Baja California. Frequencies of serum antigens have provided information about the extent of migrations of North American and Asiatic salmon in the North Pacific.

Among the more strictly biochemical approaches to comparable problems, chromatographic analyses of mucus and muscle extracts have provided further evidence for the existence of two groups of Atlantic redfish, possibly of subspecies stature. Electrophoretic analysis of hemoglobins has identified two genetically distinct subpopulations of cod in the eastern North Sea and western Baltic, and has even indicated the intermixing zone of the groups.

Other methods, although they have not yet yielded quantitative information about marine organisms, offer exciting prospects for the future. These include tissue transplantation among individuals from different subpopulations, comparisons of cell enzymes and nucleic acids, and "fingerprinting" with high voltage electrophoresis and chromatography. As research commitment and levels of sophistication of methods improve, precision of information should increase concomitantly. Since the criteria are genetic, and the factors determined usually by simple Mendelian heredity, the infraspecies structure of marine populations may soon be more clearly understood.

INTRODUCTION

subpopulation structure of marine
—the degree of discreteness or inter-
of geographic groups—is a matter
ificance to most ecological or other
ical investigations. Within the past
, increasing attention has been di-
to the use of immunological and biochemical methods to identify infraspecies groups. These approaches to taxonomic questions are based on three theses, which approach the status of axioms:

(1) Organisms have evolved biochemically as they have evolved morphologically, so that biochemical characteristics can provide as valid criteria for systematic studies as morphology.

(2) Many of these biochemical char-

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Laboratory, University of Rhode Island, Occasional Publication
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acteristics are genetically determined, and as such are not subject to environmentally-induced modifications during the life of the individual.

(3) Subpopulations or breeding groups within a species may be recognized by the existence of constant quantitative differences in frequencies of particular genes when any two groups are compared.

Research of this kind is part of a growing trend, especially evident at the recent International Congress of Zoology, toward a new systematics based on molecular morphology rather than gross morphology (Sibley 1962; Manwell 1963; Wilson and Kaplan 1963). It begins with the structure of DNA and RNA molecules and extends upward through the cell enzymes and other cell proteins. It promises to provide rather powerful added criteria for subpopulation studies since products of individual genes are being examined with physical, chemical, and immunological methods. Although techniques are specialized at the subpopulation level, variations of the methods can be used in studies at any taxonomic level, provided several criteria are satisfied:

1) material used must contain sufficient biochemical information;

2) a legitimate question must be asked of the data—not merely an underlining of the obvious;

3) techniques must be precise, rapid and simple; and

4) methods must be adapted to the systematic level of concern in the work.

This paper attempts to illustrate progress toward understanding the subpopulation structure of marine species with these newer techniques. If there has been significant progress, what principles are emerging; what have we learned about gene flow among subpopulations that we consider discrete; and what variations occur in subpopulations boundaries?

A subpopulation is here defined as "any genetically self-sustaining subdivision of a species." The emphasis is on "genetic," so any method we employ must have some genetic interpretation to be fully useful. Population genetics is of course closely related to population ecology — both deal with variability, either from the viewpoi of cause or effect.

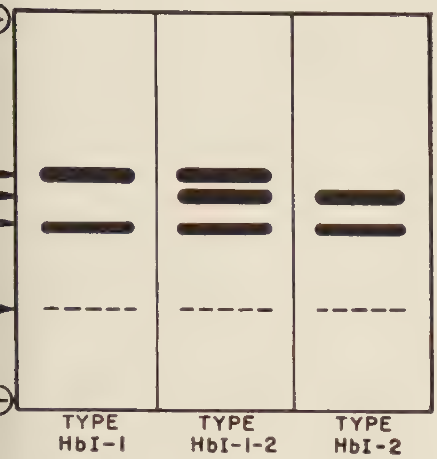
For this discussion I shall ignore the s nificant insights provided by traditior and often useful methods of morphology fin rays, vertebrae, morphometrics, otoli types, and even such productive techniqu as tagging, including parasite tags—all the interest of focusing full attention biochemical or immunological studies. though there are many tempting proaches, I propose to confine myself to few examples of those that have actua produced quantitative information abo marine subpopulations, and to present t information in some cases.

BIOCHEMICAL METHODS

Electrophoresis

Electrophoretic separations of prot mixtures have been widely used in the decade. Such separations are based on lecular size and electrical charge. Wh allowed to migrate in an electrical fie through a supporting medium such as fered agar or starch, protein componen of a complex mixture will localize at diff ent distances from a starting point, depe ing on their physical and chemical prop ties. Electrophoretic studies of serum teins, muscle proteins and hemoglobi especially of the higher vertebrates, ha disclosed species specific patterns and, some cases, variant patterns with frequ cies characteristic of particular geograp areas or races. Hemoglobins have seve important biochemical characteristics: may be isolated easily in relatively state; individual variability has been de onstrated, particularly in work with mans; and variant types have been sho to have a reasonably simple genetic ba Because of these characteristics, search been made with electrophoretic meth for variant hemoglobins in marine spe that might be useful in subpopula studies.

Probably the most definitive work hemoglobins of marine species thus fa that of Sick (1961), who identified electrophoresis three hemoglobin patt in cod. The patterns all have a slow mov component (HbII) in common, but have either one or both of two faster m ing fractions (Fig. 1). Thus three types



1. Three major patterns of hemoglobins in
lrawn from Sick (1961).

duals may be distinguished: HbI-1,
, HbI-1-2. The simplest possible gene-
lanation, as proposed by Sick, is that
alleles HbI^1 and HbI^2 which deter-
hemoglobin components HbI-1 and
. According to this hypothesis, HbI-1
IbI-2 individuals would be homozy-
and HbI-1-2 would be heterozygous.

ntitative sampling provided support
e genetic hypothesis and yielded im-
t practical information as well. Tests
ples from the eastern North Sea, Belt
d western Baltic disclosed the exis-
of two subpopulations in the fished
and even indicated the zone of inter-
of the poulations. Samples from the
rak, Kattegat and Belt Sea were ho-
eous, had similar gene frequencies
ere consistent with the Hardy-Wein-
aw, which states that with random
, and assuming no selection or muta-
fects, frequencies of allelic genes will
in proportions according to the ex-
n of the binomial, and will persist
fter in those proportions. These sam-
ere characterized by a high frequency
^{1} allele. In the Baltic proper, west-
st samples had a very low frequency
allele. Eastern Baltic samples had
ediate frequencies, an excess of ho-
tes, and did not conform to Hardy-
erg expectations — a situation ex-
l by assuming that these intermediate
s represent mixtures of Belt Sea and
subpopulations.

Though hemoglobin electrophoresis may seem the ultimate in simple techniques for subpopulation analysis, it is not of universal application, since variant patterns have not been found in several other species, including five Atlantic clupeoid species (Sindermann and Honey 1963). It is possible, however, that "fingerprinting" techniques, using a combination of chromatographic and electrophoretic methods to resolve the peptides and amino acids of the hemoglobin molecule on a two-dimensional background, may disclose more subtle variations in this and other proteins.

Paper Chromatography

Another marine problem that has proved susceptible to biochemical studies is that of the nature of two morphological types of Atlantic redfish, *Sebastes marinus*. The two types, "marinus" and "mentella" are distinguishable in certain parts of the North Atlantic by relative eye size, larval pigmentation, presence or absence of a chin spine, and depth of capture, but several of these characteristics exhibit such variability and intergradation in some ocean areas that the taxonomic status of the types has been in doubt. Schaefer (1961) using two-dimensional paper chromatography of muscle extracts was able to demonstrate significant quantitative differences in several amino acids of redfish of the two types caught in the same trawl hauls off the coast of Greenland (Table 1). He concluded from these findings that the two types could not represent a homogeneous population. O'Rourke (1961) applied other chromatographic methods to samples of gill mucus from the

TABLE 1. Results of a chromatographic comparison of skeletal muscle extracts of two redfish types from the North Atlantic by Schaefer (1961) *

Substance	"marinus" type	"mentella" type
Total nitrogen (mg/100 gm muscle tissue)	166	191
Total ninhydrin positive substances	154	96
Glycine-serine	17.9	12.4
Glutamic acid	1.9	2.8

*Values, except for total nitrogen, are expressed as mg/100 mg total extract nitrogen.

two redfish types taken in the Barents Sea, and also found significant differences in patterns obtained. Both studies thus demonstrated biochemical specificity of "marinus" and "mentella" types, suggesting at least subspecies stature for the two forms.

IMMUNOLOGICAL METHODS

Immunodiffusion

There are many ways of visualizing the reaction between a protein antigen and antibodies created against it. One of the most instructive is that of immunodiffusion —in which the reaction takes place in agar or other media as antigen and antibody diffuse from separate origins. Bands of precipitate in the agar indicate the minimum number of antigen-antibody reactions that occur, and several antigens may be compared simultaneously. Utility of the technique on the infraspecific level has been demonstrated by Ridgway, Klontz and Matsumoto (1962) who examined red salmon from the North Pacific. Most North American salmon possessed two serum antigenic factors that were missing from most Asiatic salmon (Fig. 2). Of 924 American fish, 96.8% possessed the antigens, while only 7.9% of 126 Asian fish did so. Subsequent sampling of high seas salmon in the central North Pacific near the outermost Aleuti islands disclosed intermediate frequenc indicating intermingling of Asian a American stocks of red salmon over bro areas of the North Pacific and Bering S The study had the very practical objec of providing information to the Inter tional North Pacific Fisheries Commissi about the extent of migrations in the Pac and discreteness of stocks of fish spawn in North American rivers. The infor tion formed part of the background for f ing treaty discussions with Japan, Can and the United States.

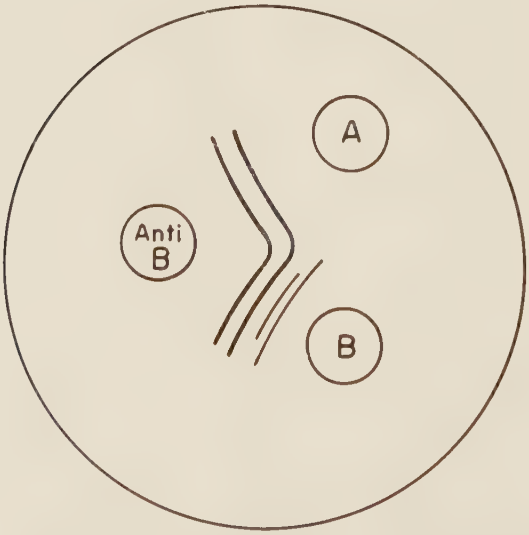


Fig. 2. Schematic representation of antigenic differences between Asiatic (A) and American (B) salmon serum when tested by immunodiffusion against an antiserum (Anti-B) made by injecting a rabbit with serum from an American red salmon. Two bands of precipitate are present in the homologous (lower) reaction that are absent from the heterologous (upper) reaction.

Blood Groups

Probably the most definitive approac the identification of marine subpopulati is that of determining blood group freq cies and, from these, gene frequencies. man blood typing has been widely and cessfully used by anthropologists, and c parable methods are being explored w marine fishes. As an example of the te niques involved, we have recently descri a blood group system for east coast sp dogfish (Sindermann and Mairs 1961). actions were obtained with rabbit anti absorbed so that reagents were crea which reacted with one or the other of erythrocyte antigens "S_1" or "S_2" (Table Using these reagents it was found that dividual dogfish possessed either, both neither antigen, being of blood types S S_1S_2, or S_0 respectively. Studies of frequ cies of each type in the Gulf of Maine, a a simultaneous comparison of gravid males and their unborn offspring (Fig.

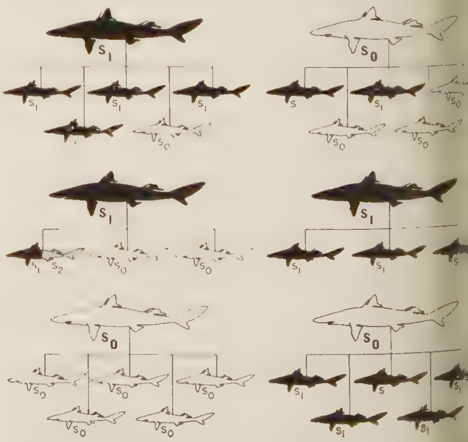


Fig. 3. Representative examples of S blood t of gravid female dogfish and their unborn offspr

2. Blood grouping reagents and blood group frequencies of spiny dogfish from the Gulf of Maine om Sindermann and Mairs 1961)

pe	Reaction with Anti-S_1 reagent	Reaction with Anti-S_2 reagent	Number of individuals of each phenotype	Frequency of each phenotype
	+	—	92	66.7%
	—	+	1	0.7%
	+	+	2	1.4%
	—	—	43	31.2%

ıe frequencies: S^1=.43, S^2=.01, S^0=.56

ed that the system was based on three S^1, S^2, and S^0. Blood grouping meth- this kind have added power in the at single samples can be examined nformity with expected frequencies ing to Hardy-Weinberg rules, and ination made as to whether the sam- s drawn from a homogeneous popu- or a mixture of two or more sub- tions.

exciting application of these tech- to high seas species has been the of Suzuki (1962) and Sprague and vay (1962)—independently studying groups of tuna—Suzuki in Japan and e and Holloway in Hawaii. Suzuki tablished a blood group system, the tem, for albacore and determined frequencies in Atlantic, Pacific and Ocean samples. One antigen (Tg3) a marked difference in frequency Atlantic samples were compared with suggesting discreteness of each stock, dicating that albacore of the Atlantic dian Oceans do not interbreed to any egree. Earlier studies had disclosed ant differences in frequencies of Tg1 g2 antigens in Pacific and Indian samples.

gue and Holloway (1962), working ipjack tuna from the central Pacific, ed another blood group system, the n, containing three phenotypes "K_1", nd "-". Frequencies in samples from waiian Islands were distinct from all reas sampled, as were those from the esas Islands. Samples from the Tua- nd Society Islands were similar to her, but distinct from others. This nce for the existence of three reproductively isolated subpopulations in the ocean area sampled.

In this way pieces of the mosaic of high seas populations are assembled. When such information is combined with results of taggings, morphological comparisons, and data from the fishery, understanding of the species moves closer to reality.

DISCUSSION

Use of other methods and research with other species extend the type of information gained from these illustrations. Whales from most of the world's oceans have been examined for frequencies of several blood factors, and subpopulation boundaries established (Fujino 1960). Intraspecific differences in serum protein antigens of oysters have been demonstrated by Numachi (1959). Atlantic herring and alewife subpopulations have been described with the use of blood grouping techniques (Sindermann 1961), as have three reproductively isolated groups of Pacific sardines off California and Baja California (Sprague and Vrooman 1962).

Biochemical and immunological techniques that are presently available are many and varied; each has its own viewpoint and perspective on a given problem; and many methods may be used simultaneously with each sample. The methods provide genetic criteria for the description of marine subpopulations—criteria with simple Mendelian heredity, as opposed to the complex inheritance of certain other quantitative characters. This genetic approach to what is fundamentally a genetic problem is enhanced by the fact that some marine species are approaching the point where they can be considered experimental populations, since methods for rearing successive generations of certain fish and shellfish are now available.

Some future areas of study are already apparent. The objective is the development of standard methods for the examination of genetic variability in any marine species. Blood group systems with greater resolving capacity will constitute a powerful tool. Possible levels of complexity are indicated by human blood group research and particularly by cattle blood typing, where extremely complex systems containing many antigens have been described (Stormont 1962) and where it is possible to characterize an individual with great precision as far as erythrocyte antigens are concerned. Tissue transplantation among individuals from different geographic areas, comparable to the work of Hildemann and Haas (1961) with frog populations, can provide information about degrees of genetic similarity. Biochemical methods on a molecular level offer other opportunities for increased precision. "Fingerprinting" with high voltage electrophoresis and chromatography, immunoelectrophoresis, and comparisons of nucleic acids and cell enzymes all offer exciting prospects for the "molecular taxonomy" of the future, even though they have not yet yielded quantitative information about marine organisms.

CONCLUSIONS

With these few examples I have tried to indicate how biochemical and immunological techniques are being used successfully in the description of marine populations. Tentative steps have been taken in quantitative studies of subpopulations, but continued efforts toward increased precision and standardization of methods are required. While blood group research has provided the most definitive information about marine vertebrates thus far, several of the more strictly biochemical methods have been used successfully and others seem very promising, particularly for invertebrate species. Research done primarily with mammals and birds has indicated that the characteristics with which we are concerned have clear and reasonably direct genetic determination. By inference, this means that unit genetic factors, amenable to quantitative studies, are available. When augmen ed by traditional but non-genetic methoc of distinguishing geographic groups, suc as morphometric, meristic or taggin studies, a closer approximation of reality i our description of marine subpopulatior should be achieved.

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Serum Hemagglutinins of the Winter Skate, *Raja ocellata* Mitchill, from the Western North Atlantic Ocean

Carl J. Sindermann and Kenneth A. Honey

Serum Hemagglutinins of the Winter Skate, *Raja ocellata* Mitchill, from the Western North Atlantic Ocean

CARL J. SINDERMANN AND KENNETH A. HONEY

Two erythrocyte isoantigens have been demonstrated in the winter skate with serum agglutinins. Individual skate sera were found, with cross-matching tests and absorption analysis, to contain both, either, or neither of two isoagglutinins. Strong natural heteroagglutinins for human and teleost erythrocytes also were found in skate sera, and a year-round study indicated that titers varied seasonally, reaching a maximum in late summer and a minimum in late winter.

IMMUNOGENETIC studies of marine fishes have been carried on continuously in several countries, particularly Japan and the United States, during the past decade (Cushing 1952; Ridgway, Cushing, and Durall 1957; Suzuki, Shimizu, and Morio 1958; Sindermann and Mairs 1959; Sprague and Vrooman 1962). Much of this research has been concerned with identification of subpopulations of economically important teleost species such as tuna, Atlantic herring, Pacific sardines, and Pacific salmon, by quantitative studies of antigen frequencies. Individual differences in erythrocyte antigens have been detected in many species, and blood-group systems have been proposed for several. The elasmobranch fishes have received only limited attention with serological methods (Sindermann 1961, Sindermann and Mairs 1961). Genetic information about blood-group antigens of the spiny dogfish (*Squalus acanthias*) was obtained by comparative study of gravid females and unborn "pups," and a blood-group system, the S system, was proposed for this species. Subsequent studies of the elasmobranchs in this laboratory have included several species of skates, and it has become apparent that these smaller cartilaginous fishes are excellent subjects for immunogenetic research. Discrete isoantibody systems have been found in the species examined, as well as high titers of natural heteroagglutinins for erythrocytes of other animals. Dogfish and skates have been maintained in marine aquaria, where they have survived repeated bleedings and injections. Since many elasmobranch species are ovoviviparous, it will be possible to compare erythrocyte antigens and other blood properties of females and their offspring, to provide an interim genetic basis for serological studies, until known crosses can be made.

This paper, second in a series on the immunogenetics of elasmobranch fishes, is concerned with certain naturally occurring hemagglutinins of winter skates, *Raja ocellata*, from the western North Atlantic Ocean.

METHODS

Skates collected at sea were bled by heart puncture, using syringe and No. 18 needle. Samples of whole blood were taken, refrigerated overnight, and the serum decanted

Table 1. Results of Cross Matching Red Blood Cells and Serum from Skates 1 Through 10, Demonstrating the Existence of Antigen SK$_a$.

Serum	Erythrocytes									
	1	2	3	4	5	6	7	8	9	10
1	–	–	–	–	–	–	–	–	–	–
2	–	–	–	+++	–	–	–	–	–	–
3	–	–	–	+++	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–

the following day. Erythrocytes were washed from clots as needed, washed twice in 1.4% saline and used in approximately 4% suspensions in saline. Skates used in laboratory experiments were brought in alive in seawater tanks on commercial trawlers, bled by heart puncture with a No. 20 needle, and tagged for future identification on the inner posterior edge of the "wings" with a coded tag.

Cross-matching tests were carried out with undiluted serum that had been inactivated for 30 min at 50°C to destroy complement. Cross reactions among skate sera and red blood cells were tested by tube agglutination, using 0.2 ml undiluted serum and 0.05 ml cell suspension for each test. Reactions were observed and recorded after 30-min incubation at room temperature and 30-sec centrifugation. Presence and degree of agglutination were recorded conventionally in the following categories: ++++, complete agglutination with a single consolidated pellet; +++, strong agglutination with several large clumps; ++, moderate agglutination with numerous smaller clumps; +, weak agglutination with many very small clumps visible macroscopically; and –, no agglutination. Saline controls were used with each test.

Skate sera were absorbed with skate erythrocytes by the addition of undiluted serum of one fish to washed cells of another fish in 1 : 1 proportions. The cell–serum suspension was incubated 10 min at room temperature, centrifuged, and the supernatant fluid (the absorbed serum) decanted and tested against

Table 2. Results of Cross Matching Re Blood Cells and Serum from Skates 1 Through 20, Demonstrating the Existence o a Second Antigen, SK$_b$.

Serum	Erythrocytes									
	11	12	13	14	15	16	17	18	19	2
11	–	–	–	–	–	–	–	–	–	–
12	–	–	–	+++	–	–	+++	–	–	–
13	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	–	–	–	–
3 (anti-SK$_a$)	+++	–	–	–	–	–	–	–	–	+

a previously removed aliquot of the cel used for absorption. One absorption wa sufficient to remove antibodies reactive wit absorbing cells, but in some cases left agglu tinins in the serum which were reactive wit cells from other individuals.

Results

1. *Isoantigens and isoagglutinins*

Evidence for a blood-group system i winter skates was first seen in cross matche of serum and cells of 10 individuals (Tabl 1). Skate 4 possessed a blood factor (tent tively labeled antigen SK$_a$) reactive wit antibodies in sera from skates 2 and Other skates in this series appeared to lac both the SK$_a$ antigen and the anti-SK agglutinin.

A second series of cross matches (Tabl 2) disclosed the existence of a second bloo factor. Cells of skates 14 and 17 were aggl tinated by serum of skate 12. The serum skate 3 of the previous series, containi anti-SK$_a$ agglutinins, reacted with cells skates 11 and 20, but not with those skates 14 and 17. This pattern of reactio suggested that the cells of skates 11 and possessed antigen SK$_a$ but that cells of skat 14 and 17 possessed a second factor (tent tively labeled antigen SK$_b$) detected by is agglutinins present in the serum of skate 1 but not by those in the serum of skate 3.

The reality of the two antigens and th specificity of their respective isoagglutini were demonstrated by an absorption anal

TABLE 3. ABSORPTIONS OF SKATE ISOAGGLUTININS BY SELECTED SKATE ERYTHROCYTES. Cells which lack SK_a or SK_b antigens have been arbitrarily designated SK_c.

Serum	Erythrocytes					
	11 (SK_a)	13 (SK_c)	14 (SK_b)	15 (SK_c)	17 (SK_b)	20 (SK_a)
Skate No. 3 (anti-SK_a) absorbed with red blood cells of						
11	–	–	–	–	–	–
13	+++	–	–	–	–	++
14	+++	–	–	–	–	++
15	+++	–	–	–	–	++
17	+++	–	–	–	–	++
20	–	–	–	–	–	–
Unabsorbed	+++	–	–	–	–	++
Skate No. 12 (anti-SK_b) absorbed with red blood cells of:						
11	–	–	+++	–	++	–
13	–	–	+++	–	++	–
14	–	–	–	–	–	–
15	–	–	+++	–	++	–
17	–	–	–	–	–	–
20	–	–	++	–	++	–
Unabsorbed	–	–	+++	-	++	–

sis of two reactive sera with selected skate red blood cells (Table 3).

Absorption of anti-SK_a serum (skate 3) with cells which lacked SK_a antigen (skates 13, 14, 15, 17) left agglutinins for SK_a antigen. Absorption of anti-SK_b serum (skate 12) with cells which lacked SK_b antigen (skates 11, 13, 15, 20) left agglutinins for SK_b antigen. Absorption of anti-SK_a serum with cells which possessed SK_a antigen removed agglutinins for absorbing cells and all others, and absorption of anti-SK_b serum with cells which possessed SK_b antigen removed agglutinins for absorbing cells and all others.

Subsequent cross matches, using serum of skate 3 as an anti-SK_a standard reagent and serum of skate 12 as an anti-SK_b standard reagent, have provided further support for the hypothesis of a two-antigen isoantibody system for this species. In preliminary work, which included tests of 75 individuals, antigen SK_b occurred more frequently in samples from Georges Bank than in samples from the central Maine coast. Thus far, two individuals have been found to possess both anti-SK_a and anti-SK_b isoagglutinins, while others possessed one or the other or neither. Many individuals appeared to lack both isoantigens and isoagglutinins.

The antigens and their respective agglutinins seem definitive enough, as presently described, to be of immediate utility in quantitative studies of antigen and gene frequencies in winter skates.

2. *Seasonal study of serum isoagglutinin titers*

Previous studies (Allen and McDaniel 1937, Bisset 1948, Cushing 1942, Smith 1940, Stone 1956) have demonstrated marked changes in serum antibody levels, related, in the case of cold-blooded vertebrates, to temperature. The usual conclusions from serological studies of poikilothermal vertebrates have been that production of immune antibodies was directly temperature dependent, and was minimal or absent below 10°C. Skates have proved to be useful subjects for examination of possible seasonal influences on antibody titers of cold-blooded vertebrates. Skates 1 through 10, cross matched for isoantigens and isoagglutinins in Table 1 of the previous section, were tagged and maintained in seawater tanks at seasonal temperatures from October 1961 through August 1962 (winter minimum temperature 0.6°C, summer maximum 17.0°C). Fish were bled and cross matched every other month during this period. No variations in isoantibody titers were found. The two individuals that possessed serum isoagglutinins when the water temperature was at its summer maximum also possessed them to the same low titer (4) at winter minimum. Fish that lacked such isoagglutinins during winter minimum temperatures also lacked them during summer maximum temperatures.

3. *Serum heteroagglutinins*

In addition to the isoagglutinins described in previous sections, sera of certain individual skates contained natural heteroagglutinins for Atlantic herring (*Clupea harengus*) and human type O erythrocytes. Great individual variations in titers of such antibodies were noted, and examples are given in Table 4. Sera of certain skates were reactive with herring cells to a dilution of 1 : 512, while others were reactive only to dilutions of 1 : 1. Furthermore, individual variations in herring erythrocyte antigens were detected by agglutinins in skate sera. Cells of herring 2 and 4 (Table 4) were unreactive with any skate serum tested. Herring cells had been previously tested with reagents (absorbed rabbit anti-herring sera) used in routine detection of an antigen labeled "C" (Sindermann and Mairs 1959). Herring 2 and 4 were C-negative, while herring 1 and 3 were C-positive. This relationship of herring C antigens to skate heteroagglutinins was further tested with 50 individual herring blood samples. In every case herring cells lacking the C antigen were unreactive with skate sera, while those possessing the antigen were reactive, although to varying titers, as indicated in the examples given in Table 4.

Seasonal variations in natural heteroagglutinin titers also were examined, using skates 21 through 29. These fish were tagged, maintained in seawater tanks at seasonal temperatures from October 196 through August 1962, bled periodically, and tested for heteroagglutinins reactive with herring and human erythrocytes. A marked decline in heteroagglutinin titer occurred during the winter months. Maximum titers

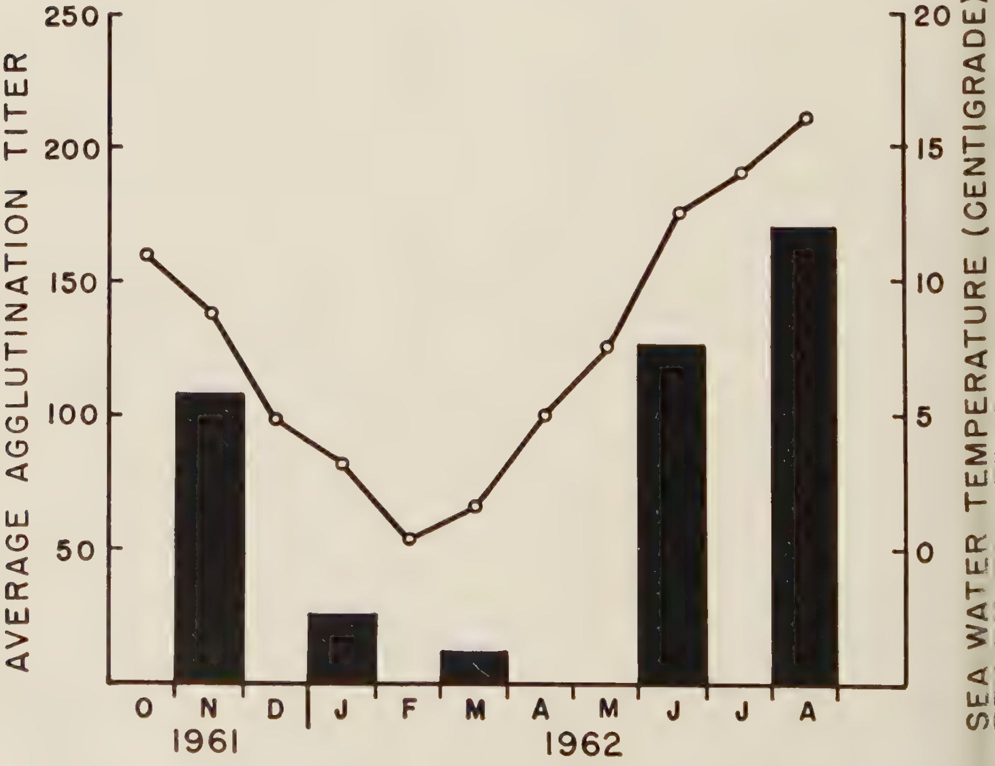

Fig. 1. Monthly mean seawater temperatures (solid line) and average skate serum heteroagglutinin titers (bars) when tested against human type O erythrocytes.

TABLE 4. HETEROAGGLUTININ TITERS OF INDIVIDUAL SKATE SERA AGAINST ATLANTIC HERRING AND HUMAN TYPE O ERYTHROCYTES (NOVEMBER 1961). Titers are expressed as reciprocals of the highest serum dilution in which agglutination occurred.

Skate Serum	Erythrocytes				
	Herring 1	Herring 2	Herring 3	Herring 4	Human O
21	512	0	128	0	256
22	16	0	16	0	4
23	256	0	128	0	64
24	16	0	4	0	0
25	32	0	16	0	0
26	64	0	32	0	128
27	4	0	4	0	256
28	4	0	1	0	1
29	8	0	16	0	64

in January and March did not exceed 32 and the titers for each individual fish had declined by at least three doubling dilutions from their previous autumn level. Heteroagglutinin titers increased in spring and exceeded the previous autumn level by June (Fig. 1).

DISCUSSION

The elucidation of an isoantibody system for winter skates adds another facet to immunogenetic studies of elasmobranch fishes. The existence of discrete erythrocyte antigens and serum isoagglutinins in skates, as well as in dogfish (Sindermann and Mairs 1961), offers the promise that these very important tools for systematic studies may be of common occurrence in elasmobranchs. Knowledge about subpopulations within species, and the extent of their intermixing, may be obtained by quantitative studies of erythrocyte antigen and gene frequencies. Such studies have become standard in anthropological research, and are becoming so with certain teleost species (Suzuki *et al.* 1959, Sprague and Vrooman 1962). Several of the larger cartilaginous fishes, the sharks in particular, should lend themselves to immunogenetic methods of subpopulation analysis. Above the species level, studies of serum proteins with a variety of serological methods comparable to those used with Atlantic clupeoid fishes (Mairs and Sindermann 1962) could provide additional information about natural relationships among elasmobranchs.

A year-round examination of serum hemagglutinins of skates held in experimental tanks at seasonal seawater temperatures has indicated that heteroagglutinin titers varied seasonally. Several previous studies have demonstrated that production of immune antibodies by poikilothermal vertebrates is related directly to temperature, and the present work suggests a direct temperature relationship for "natural" heteroagglutinin titers, although other environmental variables could be involved. The very low isoagglutinin titers found in this study would make variations difficult to detect, and therefore do not provide additional evidence concerning the temperature relationship. A logical elaboration of the present study to provide more definitive information would be an examination of seasonal variations in titers of skate immune antibodies, including isoimmune agglutinins.

SUMMARY

Certain of the naturally occurring hemagglutinins of winter skates (*Raja ocellata*) have been examined. An isoantibody system has been identified by cross matches of cells and sera, and by absorption analysis of reactive sera. The system contains two erythrocyte antigens tentatively labeled SK_a and SK_b, and their corresponding specific serum isoagglutinins anti-SK_a and anti-SK_b.

Skate sera also contained high titers of naturally occurring heteroagglutinins for Atlantic herring and human erythrocytes. Such heteroagglutinins distinguished individual variations in herring erythrocyte antigens that paralleled those disclosed by routine testing reagents prepared from rabbit anti-herring sera.

Skate heteroagglutinin titers varied individually and seasonally, with a maximum in late summer and a minimum in late winter. Seasonal variations in isoagglutinin titers were not detected.

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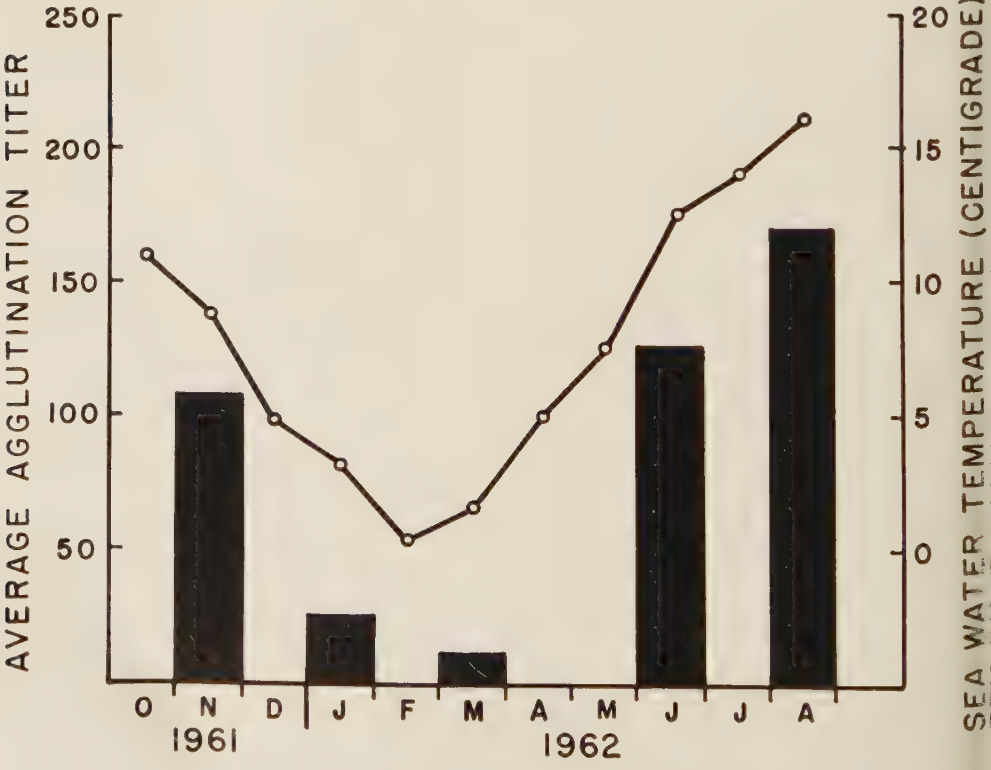

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p. 320

FAUNA OF U.S.S.R. FISHES. VOL. II. NO. 1. CLUPEIDAE. *By A. N. Svetovidov. 1952. Zoological Institute of the Academy of Sciences of the U.S.S.R. Translated from Russian. Published for the National Science Foundation, Washington, D. C. 1963. iv + 428 pp., 54 figs., 53 plates. Available from the Office of Technical Services, U. S. Department of Commerce, Washington, D. C. OTS 61-11435. $4.25.*

This translation is one of a series on Russian fishes provided through the Israel Program for Scientific Translations. (New translations will be listed in the Book Review Section of the *Transactions* as they are released.)

Svetovidov published this work in Russian in 1952. His 93-page Introduction is well organized and provides an excellent background of the widely distributed herring family. He begins with an historical survey of the classification of the family and follows with a discussion of its taxonomy and principles of classification. The next three headings concern the geographical distribution, biology, and economic importance of these fishes. At the end of the Introduction is a Bibliography listing 105 Russian authors and 93 publications in other languages, including many North American authors.

The section entitled "Systematics, Family Clupeidae—The herrings" begins on page 94 with a discussion of family characteristics and a provisional division of subfamilies: Dussumieriinae, Clupeinae, Pellonulinae, Alosinae, Dorosomutinae, and Pristigasterinae. (Some of these are regarded as tribes rather than subfamilies.) The remainder of the Systematics section is divided into descriptions of 11 genera: *Etrumeus, Sprattus, Clupea, Harengula, Sardinella, Sardinops, Sardinia, Clupeonella, Alosa, Clupanodon,* and *Ilisha.*

The characteristics of each genus are listed, including a description of the skeleton under a separate heading. Synonyms and early references are listed for each species within the genus, as are the specific characteristics. Comments follow on the species distribution, biology, and economic importance.

Svetovidov's work will be of particular interest to taxonomists concerned with the order Clupeiformes, but will attract the attention of biologists and ecologists as well. His success in presenting a useful reference to several disciplines is perhaps inherent in his approach to systematics. In the section on principles of classification he states ". . . a classification system must be based on a whole complex of ypical morphological characters functionally related o the biology of the examined group and developing as a result of the interaction of the organism and ts environment. . . ."

Considering the scope of the task undertaken, Svetovidov has provided an excellent account of the herring family. His detail on references to North American species is lacking somewhat, but is perhaps consistent with the relatively greater emphasis these species attract in other parts of the world.

There is a need in American literature for similar broad taxonomic efforts, and perhaps the work of Svetovidov and others will help to stimulate and rekindle such an interest.

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ꞃNARD E. SKUD, U. S. Bureau of Commercial sheries Biological Laboratory, Boothbay Harɒr, Maine.

avior of marine organisms during a solar eclipse. y title only)

he behavior of herring, *Clupea harengus*, and green crab, *Carcinus maenas*, was observed dur- the solar eclipse of July 20, 1963. Herring were ed in a holding pen which was visually sepa- l into four quadrants, each with a surface and om layer. Crabs were held in a tank with a and gravel bottom, and a "shelter" in one er. Activity was recorded at 15-minute inter- The eclipse occurred from 4:45 to 6:45 P.M.; ity at 4:45 P.M.

fore totality, herring were dispersed through- the two quadrants exposed to direct sunlight. en minutes before totality, some herring swam the shaded quadrants. At totality, a few indi- als moved to the surface and began to school. wing totality, the schooling pattern ceased and ish were dispersed as before.

ie crabs elicited no response during the eclipse remained hidden in the shelter until 8:30 P.M. 50-second period of darkness at totality was rently of too short a duration to elicit this urnal activity.

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THE TAXONOMIC STATUS OF *LEUCICHTHYS MACROPTERUS*, A CISCO OF LAKE ERIE.—The species *Leucichthys macropterus* was described by Bean (1916, *Proc. Biol. Soc. Wash.* 24:25–26) from a single specimen taken from Lake Erie in December 1914. The fish was caught by a commercial fisherman of Erie, Pennsylvania, in gill nets set near the New York–Canadian boundary. Because of its unusually long fins, he gave it to the Superintendent of the State Hatchery at Erie. It was preserved in formalin and subsequently given to Bean for description. Bean recognized the fish as a "singular form" and described it as a new species.

Koelz (1929, *Bull. U. S. Bur. Fish.* 43(2): 297–643) observed that, "No other individuals like it have been collected and none have been seen by any of the numerous fishermen interviewed," by him on Lake Erie. Koelz concluded that *L. macropterus* was a "monstrosity" and it was subsequently ignored in the literature.

Interest in this specimen was renewed when *L. alpenae* was recently discovered in Lake Erie (Scott and Smith 1962, *J. Fish. Res. Bd. Canada* 19(6):1013–1023). The question arose whether *L. macropterus* was an aberrant *L. alpenae* or *L. artedi*, the only two ciscoes that occur in Lake Erie. The gill raker count of 30 reported by Bean (*op. cit.*) fell within the range of 30–39 for *L. alpenae* (Scott and Smith *op. cit.*), and outside the greatest range 37–53 reported for *L. artedi* (Scott 1950, Ph.D. thesis, University of Toronto). Thus, Scott and Smith considered that *L. macropterus* may have been an aberrant *L. alpenae* rather than *L. artedi* as previously assumed. It has been observed subsequently that the description of *L. macropterus* by Bean in 1916 antedates the description of *L. alpenae* (Koelz 1924, *Occas. Pap. Mus. Zool., Univ. Mich. No. 146*, pp.). Therefore, the question arises as to whether *alpenae* is a junior synonym of *macropterus*, even though the latter was used to describe an obviously abnormal fish.

I reexamined the type specimen of *L. macropterus* (USNM No. 76845) and found it was an aberrant *L. artedi*. The gill raker count of 8 + 22 = 30 reported by Bean was obtained from a poorly excised section of the right gill arch. I also found 30 gill rakers on this segment which obviously lacked the short rakers characteristic of the extremities of coregonid gill arches. I carefully excised the left gill arch and counted 16 + 31 = 47 gill rakers and found that other measurements and counts (which agreed with those in Bean's description) and its general appearance, except for fin length, were typical of Lake Erie *L. artedi*. Scott and Smith (*op. cit.*) found the greatest differences between *L. alpenae* and *L. artedi* in gill raker counts, length of the lower gill arch, and length of the center gill raker, and that the discrimination index:

$$F = R + \left(\frac{100CR}{LA}\right)$$

where: $F =$ a discriminant function
$R =$ number of gill rakers
$CR =$ length of center gill raker
$LA =$ length of lower gill arch

similar to the index used by Dottrens (1959, *Rev. Suisse Zool.* 66(1):1–66) for European coregonids, gave broad and complete separation of the Lake Erie ciscoes. The value of F of 89 for the specimen described as *L. macropterus*, compared to 64–77 (mean 69.2) for *L. alpenae* and 82–96 (mean 89.5) for *L. artedi*, supports the identification as an aberrant *L. artedi*. I conclude that the fish described as *L. macropterus* was, in fact, an aberrant *L. artedi* and does not represent a valid species.

The anomaly of long fins is rare but not unknown in ciscoes of the Great Lakes. I collected a specimen of *L. hoyi* (UMMZ No. 180625) in Lake Michigan in 1961 that had abnormally long left pectoral, dorsal, and caudal fins which had *per mill* ratios of fin length to standard length of 467, 260, 597, respectively. The lengths of the right pectoral (195) and pelvic (169) were normal for this species, but the anal fin (188) exceeded the longest previous measurement (155) for *L. hoyi*. The longest pectoral and dorsal fins that I have encountered in measurements of over 1,000 ciscoes of the Great Lakes were 257 and 228, respectively, for *L. kiyi*, the cisco characterized by the longest fins.

Fin lengths for the specimen described as *L. macropterus* were: pectoral, 379; pelvic, 433; anal, 317; dorsal, 396; caudal, 375.—

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Status of the Deepwater Cisco Population of Lake Michigan

Stanford H. Smith

Status of the Deepwater Cisco Population of Lake Michigan

Stanford H. Smith

U. S. Bureau of Commercial Fisheries
Biological Laboratory, Ann Arbor, Michigan

ABSTRACT

The species and size composition and the abundance of the cisco (*Leucichthys* spp.) population of Lake Michigan have undergone drastic changes since the sea lamprey became established in the 1940's. The changes were measured by the catches of gill nets of identical specifications fished at the same seasons, depths, and locations in 1930–32, 1954–55, and 1960–61. The two largest ciscoes (*johannae* and *nigripinnis*), exploited heavily in a highly selective fishery from the midnineteenth century to the early 1900's, were only sparsely represented in the catch in the 1930's and were absent from catches of the comparison surveys in 1954–55 and 1960–61. The species of intermediate size (*alpenae*, *artedi*, *kiyi*, *reighardi*, and *zenithicus*) constituted about two-thirds of the cisco stocks of the deepwater zone in the 1930's but declined to 23.9 and 6.4 percent in the 1950's and 1960's, respectively. Major causes of change were the increased fishing pressure and sea lamprey predation that accompanied the disappearance of the lake trout. The small, slow-growing cisco (*hoyi*)—the primary food of lake trout—which was not fished intensively, and was too small to suffer greatly from sea lamprey predation, increased from 31.0 percent of the catch in the 1930's to 76.1 percent in the 1950's and 93.6 percent in the 1960's. Consequences of the extreme imbalance of the cisco population have been a reduction in mean size of all species, extension of the range of the very abundant *hoyi* (formerly most abundant in moderately shallow areas) to almost all depths and sections of the lake, and possibly introgressive hybridization among the various species. The primary change in the fishery has been a shift from gill nets to more extensive use of trawls which can take the now abundant smaller fish.

INTRODUCTION

intensive commercial fishery and the ation by the sea lamprey have caused vast ges in the species composition, abun- e, and biology of the deepwater ciscoes of Michigan. Changes in cisco stocks early century were not measured accurately, nferences about them can be drawn from ds of the fishery. Measures of more re- changes have been made by fishing gangs ıen gill nets of identical specifications and sizes at the same locations and seasons 930–32, 1954–55, and 1960–61.[1]

e deepwater ciscoes (known commer- as chubs) of Lake Michigan have sup- d a continuing commercial fishery since time near the mid-1800's. Gill nets with es greater than 3 inches (stretched mea- were used in early fishing to catch the r fish. As the fishery developed, the ber of larger ciscoes declined and mesh sizes were decreased to maintain the catch. By 1950, the most common mesh was 2½ inches, and by the end of the decade 2⅜-inch mesh was permitted in some areas. As large ciscoes became scarce and small ciscoes more abundant, gill net fishing grew less profitable. A limited otter trawl fishery that could catch small ciscoes efficiently had become established by 1960. There have been no mesh regulations on trawls, but trawling was limited to deeper waters and the catch restricted to unprotected species such as ciscoes (catches are mostly small ciscoes called bloaters in the fishery), and the alewife and smelt which also could not be taken profitably by gill nets.

In 1926–39, when complete records were available, deepwater cisco catches varied from 1.6 to 6.2 million pounds. In the 1940's, the catch rose steadily from 1.6 to 7.4 million pounds, reflecting the shift in fishing as lake trout stocks declined. The catch averaged 10.2 million pounds in the 1950's and rose above 12 million pounds in the early 1960's as trawling became established.

Eight species of deepwater ciscoes (*Leuc-*

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r a description of the 1930–32 and 1954–55 s, which established the pattern followed in 960–61 work, see Moffett (1957).

ichthys alpenae, L. artedi, L. hoyi, L. johannae, L. kiyi, L. nigripinnis, L. reighardi, and *L. zenithicus*), have been described from Lake Michigan (Koelz, 1929). The shallow-water cisco or lake herring (*L. artedi*) is found at all depths but it has never been abundant in the deeper areas (below 25 fathoms) where other ciscoes are common. Although *artedi*[2] is not considered a deepwater cisco, it is included in subsequent discussion where pertinent, and in some tables to show total catch. *Artedi* is not included wherever the term "deepwater ciscoes" is used.

Growth rates have been determined for four of the deepwater ciscoes. Of these, *hoyi* (Jobes, 1949a) grows the slowest and seldom attains large size, and *kiyi* (Deason and Hile, 1947), *reighardi* (Jobes, 1943), and *alpenae* (Jobes, 1949b) have increasingly rapid growth in the order given, and attain medium size. Average lengths[3] of the stock in 1930 when all species were well represented were: *hoyi* (8.0 inches), *kiyi* (10.2 inches), *reighardi* (10.5 inches), *alpenae* (10.8 inches), *zenithicus* (11.2 inches), *johannae* (11.4 inches), and *nigripinnis* (13.1 inches) (Figure 1). *Hoyi* and *reighardi* were most common in the upper zone of the deepwater areas; *alpenae, johannae,* and *zenithicus* inhabited intermediate depths; and *kiyi* and *nigripinnis* were predominantly deepwater forms.

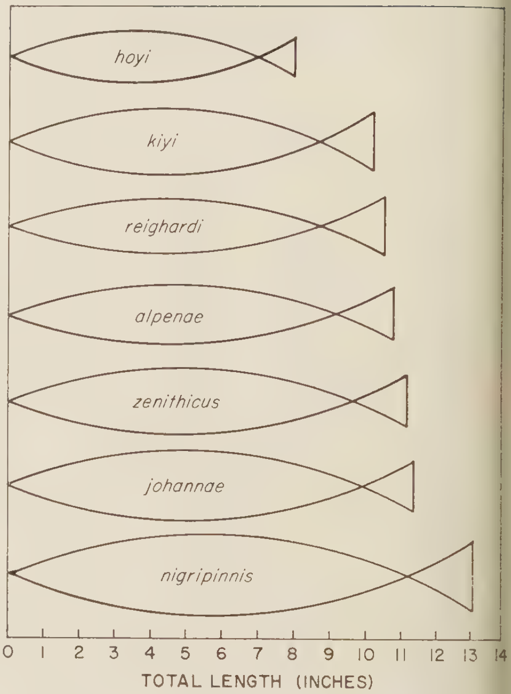

FIGURE 1.—Average length of various species of deepwater ciscoes of Lake Michigan in 1930.

Other species in the deeper waters of Lake Michigan are the lake trout (*Salvelinus namaycush*), burbot (*Lota lota*), and the deepwater sculpin (*Myoxocephalus thompsoni*). Species abundant in shallower areas of the lake, but sometimes mingling with deepwater species are, in addition to *artedi*, suckers (*Catostomus catostomus* and *C. commersoni*), walleyes (*Stizostedion v. vitreum*), whitefish (*Coregonus clupeaformis*), and yellow perch (*Perca flavescens*). Of three recent invaders, the sea lamprey (*Petromyzon marinus*), that attained abundance by the late 1940's, is the most persistent inhabitant of the deepwater zone as it rarely enters shallow water except toward late fall and winter when it congregates preliminary to entering streams to spawn in the spring. The alewife (*Pomolobus pseudoharengus*), that became abundant in the late 1950's, and smelt (*Osmerus mordax*), which reached abundance in the 1930's, are common in the deeper waters except that both move to shallow areas in the spring prior to spawning. Smelt more than a year old are found in or near the thermocline in the summer. Of the exotic species, only the alewife has attained an abundance approaching the numbers of deepwater ciscoes.

METHODS IN COMPARISON SURVEYS

The abundance of deepwater ciscoes in southern and central Lake Michigan was measured by fishing experimental gill nets at 25 and 50 fathoms off Grand Haven in 1960 at 25 and 60 fathoms off Ludington in 1961, where the same gill nets were fished in 1954 and 1955, respectively. Gill nets of identical specifications were fished at these locations in 1930–31. Similarly, measures of abundance were obtained from northern Lake Michigan

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[2] Specific names are used to identify species. Common names of the industry vary greatly and often apply to more than one species.

[3] Average lengths of all fish taken in all experimental gill nets fished in southern and central Lake Michigan in 1930.

BLE 1.—*Number of ciscoes taken in Lake Michigan in identical gangs of gill nets in different periods*
pressed as catch per 1,530-foot gang with equal amounts of 2½-, 2⅝-, and 2¾-inch mesh in the north end, and as catch per 2,550-ot gang with equal amounts of 2⅜-, 2½-, 2⅝-, 2¾-, and 3-inch mesh in the central and south areas]

cies	North end[1]			Central and south					
				25 fathoms[2]			50–60 fathoms[2]		
	1932	1955	1961	1930–31	1954–55	1960–61	1930–31	1954–55	1960–61
nae	24.3	0.8	1.3	84.0	27.7	3.2	47.0	21.8	3.5
di	0.6	0.7	5.4	4.7	1.7	6.1	0.3	4.0	5.2
i	26.8	54.4	209.3	187.1	562.6	431.4	90.3	430.4	353.2
nnae	0.4	0.0	0.0	21.2	0.0	0.0	4.7	0.0	0.0
	6.6	3.8	2.3	8.6	9.6	1.5	73.7	79.2	19.2
ipinnis	0.3	0.0	0.0	1.8	0.0	0.0	3.6	0.0	0.0
hardi	12.0	6.5	4.5	213.2	20.4	6.8	60.5	16.1	4.0
thicus	9.7	1.0	1.2	32.1	18.3	3.3	8.8	5.9	3.6
dentified[3]	4.2	0.2	0.3	19.5	10.7	0.6	14.7	5.9	0.5
al	84.9	67.4	224.3	572.2	651.0	452.9	303.6	563.3	389.2

Nets set at 50 fathoms off Manistique and Charlevoix, and southwest of Beaver Island.
Nets set at 25 and 50 fathoms off Grand Haven and 25 and 60 fathoms off Ludington.
Ciscoes were unidentified when they were badly damaged in capture or handling, or when their identity was uncertain. greater numbers of unidentified fish in 1930–31 and 1954–55 were due largely to inexperience of new workers.

1932, 1955, and 1961, at 50 fathoms off nistique, southwest of Beaver Island, and Charlevoix. All gangs in each survey of thern and central Lake Michigan included shes of 2⅜, 2½, 2⅝, 2¾, and 3 inches retched measure). The largest (3-inch) l smallest (2⅜-inch) mesh sizes were not ned in northern Lake Michigan in 1932; s, comparisons of the three periods for thern Lake Michigan are based wholly on three intermediate mesh sizes. All data are usted to reflect the catch of 510 linear t (the length of each experimental net in 30–32) of each mesh unless otherwise ed.

ABUNDANCE OF DEEPWATER CISCOES

The abundance of various species of deep-ter ciscoes has changed greatly since the nery began in the 1800's. The two largest cies (*nigripinnis* and *johannae*) which ported the earliest fishery (Hile and ttner, 1955) constituted only a small seg-nt of the population in 1930–32 (Table 1). hough a few *nigripinnis* and *johannae* were erved in catches of experimental and com-rcial gear in the early 1950's,[4] none were en in the gill nets used for this study in 4–55 and 1960–61. Other species of deep-er ciscoes except *hoyi* showed sharp de-es in abundance from 1930–32 to 1960–61 ble 1). The numbers of *hoyi* increased sharply after 1930–32. *Artedi,* although not abundant in the deep water of Lake Michigan, also showed a substantial increase.

Hoyi made up only 31.0 percent of the catch of experimental nets in 1930–32 but increased to 76.1 and 93.6 percent in 1954–55 and 1960–61, respectively (Table 2). In general, *hoyi* showed the strongest dominance in the central and south areas in 1954–55, and in the north in 1960–61. The trend toward increasing dominance of *hoyi* appeared in all areas. Species other than *hoyi* that represented 69.0 percent of the catch in 1930–32 made up only 6.4 percent in 1960–61; the representation was smallest (5.1 percent) in the north end of the lake (Table 2).

The abundance index of *hoyi,* expressed as percentage of the 1930–32 catch, increased substantially at all locations except one (Charlevoix) in 1954–55, and at all locations in 1960–61 (Table 3). Changes in abundance varied greatly at different locations, but the average change was greatest for *hoyi* in the central and south sections in 1954–55 (index value, 400 percent) and in the north in 1960–61 (index value, 887 percent).

The abundance of species other than *hoyi* declined in 1954–55 and 1960–61 (Table 3). The average abundance of other species in central and south areas was 43 percent in 1954–55 and declined further to 13 percent in 1960–61. The abundance of other species in the north changed little—22 percent in 1954–55 and 25 percent in 1960–61.

The abundance of all species in the central and south areas reached 156 percent in 1954–

The last *johannae* was seen in 1951 (Moffett,) and the last *nigripinnis* recorded from Lake nigan was taken during the 1955 survey of which study was part.

TABLE 2.—*Percentage contribution of* hoyi *to the cisco catch of experimental gill nets in 1930–32, 1954–55, and 1960–61*

Location	Depth (fathoms)	*hoyi* 1930–32	1954–55	1960–61
North				
Manistique	50	39.0[1]	79.5	94.1
Island area	50	32.2[1]	73.5	94.2
Charlevoix	50	20.9[1]	65.4	96.3
Central and south				
Ludington	25	29.2	90.8	93.1
Ludington	60	26.3	84.7	89.8
Grand Haven	25	34.8	81.3	96.6
Grand Haven	50	34.6	57.4	90.9
Average				
North		30.7	72.8	94.9
Central and south		31.2	78.2	92.6
All data		31.0	76.1	93.6

[1] The 2⅜- and 3-inch meshes were not fished in northern Lake Michigan in the 1930's. In areas where all five meshes were fished, the percentage contribution of *hoyi* to the catch was about the same in the three middle meshes as in all five.

55 but returned to approximately the 1930–31 level in 1960–61 (107 percent—Table 3). The abundance of all species in the north was below the 1932 level in 1955 (81 percent), but increased sharply to 267 percent in 1961.

FACTORS OF CHANGES IN ABUNDANCE

A selective fishery for the larger individuals of a stock should, if intensive enough, reduce the number of large fish. If the stock were composed of several similar but biologically distinct species that were equally vulnerable except for size, the fishery would select against the species that attained larger size and favor the smaller species. To examine these assumptions Figure 2 was constructed, in which species are arranged in order from the largest (*nigripinnis*) to the smallest (*hoyi*) average size in the population (Figure 1). The area of the circles represents the relative abundance (percentage) of each species for each time period. The indication that all species were equally represented prior to 1900 is merely a graphical convenience that provides reference to a period when abundance of the various species was undoubtedly more nearly uniform.

Selection against larger fish is shown clearly by Figure 2, for after the disruption of the virgin stock (post 1900) the representation of larger fish decreased with time, and for each period the number of fish increased as size decreased. The only exception is *kiyi* in 1930–32. The true abundance of *kiyi* in the lake as a whole is not reflected in Figure 2 as *kiyi* is the species most characteristic of the deepest areas which were not sampled adequately in the experimental fishing on whic these comparisons are based. The slow-growing *hoyi* (Jobes, 1949a) was the only specie to increase with time.

Before the commercial fishery started in th deep waters of Lake Michigan, the larg ciscoes had no predators, but the small ciscoe were the primary food of the lake trout an burbot (Van Oosten and Deason, 1938), bot of which were abundant in the deepwate community. The removal of large number of lake trout (5.2 to 9.0 million pounds prio to 1900), by the early fishery, relieved preda tion on small ciscoes and strengthend thei competitive position with large ciscoes. Th fishery also took substantial numbers of larg ciscoes (incomplete records of 1.4 to 3.0 mi lion pounds prior to 1900) by gill nets wit meshes of 3 inches or more. This selectiv fishing also favored small ciscoes, and thu augmented the food supply of the lake trou and burbot. Burbot were never important i the fishery (landings seldom over 50,00 pounds though actual catches were muc greater) as little market existed for then Thus the early fishery favored the small ci coes by removing lake trout, burbot, and larg ciscoes, and created a situation helpful to th lake trout by favoring its food supply.

The influences of the early fishery may b reflected by a continuing catch of substantia quantities of lake trout in the early 1900 (4.8 to 11.7 million pounds, 1900–1945), an a reduction in large ciscoes (Figure 2). I fact, the largest cisco, *nigripinnis*, was scarcel represented in the catches in 1930–32, an *johannae* and *zenithicus* were poorly repr sented (Table 1, Figure 2). The slow-growin *hoyi* constituted 31.0 percent of the catc (Table 2) and was taken in substantial nun bers in all areas (Table 1) in 1930–32.

Selective destruction of lake trout, burbo and large chubs was increased greatly as t sea lamprey invaded Lake Michigan and a tained abundance in the 1940's and ear 1950's. The lake trout (Eschmeyer, 1957) an burbot (Moffett, 1957) were extremely scar by the early 1950's. Predation on small ci coes was practically eliminated. Concurre with the decline of the lake trout, a shift the commercial fishery to large cisco

TABLE 3.—*Changes in availability of* hoyi *and other species of ciscoes in Lake Michigan from 1930–32 to 1954–55 and 1960–61*

[Numbers of ciscoes per gang of gill nets in 1954–55 and 1960–61 expressed as percentages of catches in the same gear in 1930–32]

Location	Depth (fathoms)	*hoyi*		Other species		All species	
		1954–55	1960–61	1954–55	1960–61	1954–55	1960–61
North							
Manistique	50	420	1,309	23	31	106	299
Island area	50	236	808	30	26	96	278
Charlevoix	50	88	544	13	19	42	224
Average	—	248	887	22	25	81	267
Central and south							
Ludington	25	331	319	14	10	107	100
Ludington	60	1,136	475	73	19	353	139
Grand Haven	25	286	193	28	3	77	68
Grand Haven	50	163	345	56	21	90	122
Average	—	400	333	43	13	156	107

brought a sharp rise in production from 1.6 million pounds in 1941 to 10.3 million pounds in 1951. As the larger ciscoes became less plentiful, the mesh sizes of gill nets were reduced to 2⅜ inches in some areas in the 1950's.

The changes that accompanied establishment of the sea lamprey in Lake Michigan intensified greatly the selective forces of the early fishery. The small *hoyi* had possessed the reproductive potential to maintain its numbers under heavy predation by lake trout and burbot, prior to commercial fishing. It was little affected by the increased commercial fishing which sought large ciscoes or by predation by the sea lamprey which rapidly grows to such a size when it must feed on larger fish (Moffett, 1957). Consequently *hoyi* dominated the deepwater cisco population by 1954–55 and constituted 57.4 to 90.8 (average 76.1) percent of the take at various locations (Table 2). Increased competition from *hoyi* undoubtedly added to the forces of the fishery and lamprey predation that reduced the abun-

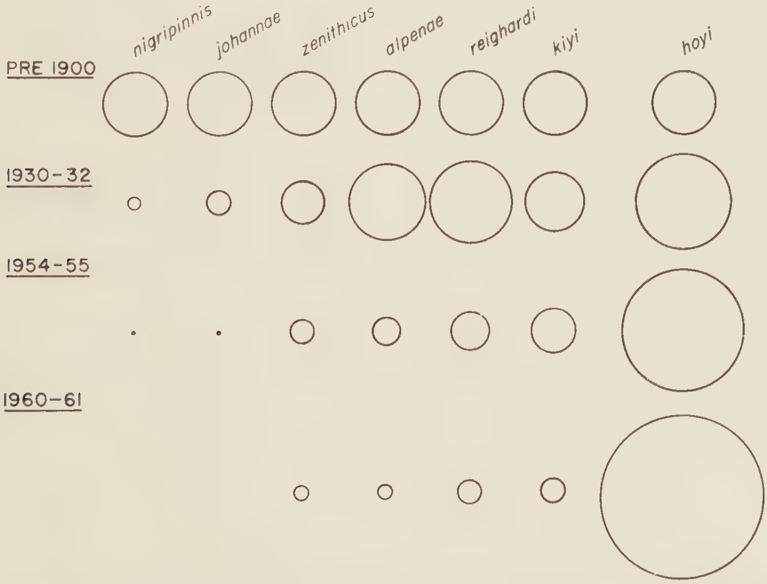

FIGURE 2.—Average species composition (percentage) of deepwater ciscoes of Lake Michigan in various periods. Species are arranged in order of their average size in the population from the largest (*nigripinnis*) to smallest (*hoyi*). Assumption of equal abundance of species prior to 1900 is for illustration only. *Nigripinnis* and *johannae* were not taken in 1954–55 in experimental nets used for this study—their known presence in the lake from other gear fished in the early 1950's is shown by dots.

dance of all larger ciscoes except *kiyi*. *Kiyi*, which grows almost as slowly as *hoyi*, did not decline in the southern and central area between 1930–32 and 1954–55 (Table 1). *Kiyi* was little sought by the fishery and inhabited the deepest areas where it may have received some relief from lamprey predation. *Nigripinnis* and *johannae* became extremely scarce. Few were seen in the early 1950's, and none were taken in the comparison fishing in 1954–55.

The continued decline of large ciscoes was reflected in a reduction in the commercial catch from 10.9 million pounds in 1956 to 7.8 million pounds in 1959. This drop occurred despite the greater use of smaller meshes in gill nets, the inclusion in the marketed catch of small fish that had been discarded previously, and the start of a trawl fishery in Wisconsin that took 1.4 million pounds of ciscoes in 1959, most of which were small—undoubtedly *hoyi*.

The comparison survey of 1960–61 showed that all species of deepwater ciscoes except *hoyi* had remained scarce or reached new lows in abundance (Table 1). *Nigripinnis* and *johannae* appeared to be extinct. *Hoyi* dominated the population in all sections of the lake that were sampled and constituted 89.8 to 96.6 percent of the catch (Table 2). The dominance of *hoyi* was greater in the north (94.9 percent) than the central and southern areas (92.6 percent). Despite the low abundance of species other than *hoyi* there was still evidence of size selection in 1960–61 when the abundance of each species increased as the average size decreased (Figure 2).

As a consequence of this extreme imbalance in the cisco population, the trawl fishery was extended to the State of Michigan waters of southern Lake Michigan (south of Ludington, Michigan), in 1960. Combined trawl catches of deepwater ciscoes for Michigan and Wisconsin have been:

1960	7,119,500 pounds
1961	6,218,000 pounds
1962	4,769,400 pounds

TABLE 4.—*Length distribution of ciscoes of diffe*
sections of Lake Michigan in 1930–32, 1954
and 1960–61

[Fish from 2½-, 2⅝-, and 2¾-inch mesh combined. Freq
cies expressed as percentage of fish in each length gr

Total length (inches)	North			Central and sout	
	1932	1955	1961	1930–31	1954–55
5.0– 5.4	<0.1	—	—	—	—
5.5– 5.9	—	—	—	—	0.1
6.0– 6.4	—	—	—	0.3	0.7
6.5– 6.9	—	0.4	<0.1	2.1	4.0
7.0– 7.4	<0.1	1.3	0.3	6.1	13.7
7.5– 7.9	0.4	8.3	4.2	5.5	15.2
8.0– 8.4	1.0	15.3	10.5	3.2	13.5
8.5– 8.9	1.2	17.2	12.0	2.9	13.5
9.0– 9.4	1.7	15.1	14.6	2.8	10.6
9.5– 9.9	2.5	15.1	23.8	5.5	10.7
10.0–10.4	9.0	16.2	20.4	13.0	8.5
10.5–10.9	21.4	7.4	9.3	18.2	5.9
11.0–11.4	20.2	2.8	3.4	17.7	2.1
11.5–11.9	14.1	0.9	0.8	11.7	1.1
12.0–12.4	10.3	0.2	0.4	6.9	0.3
12.5–12.9	8.5	0.1	0.1	2.1	0.1
13.0–13.4	4.4	—	0.1	0.6	—
13.5–13.9	2.4	—	—	0.5	—
14.0–14.4	1.3	—	—	0.3	—
14.5–14.9	0.6	—	—	0.2	—
15.0–15.4	0.3	—	—	<0.1	—
15.5–15.9	0.3	—	—	0.2	—
16.0–16.4	0.2	—	—	—	—
16.5–16.9	<0.1	—	—	<0.1	—
17.0–17.4	0.1	—	—	—	—
18.5–18.9	<0.1	—	—	—	—
Average length	11.4	9.3	9.5	10.3	8.7

The decline in the trawl catch from 1960 to 1962 does not reflect a decrease in the stocks. The market for large quantities of small ciscoes was not well established; the drop in the catch reflected decreasing demand. When trawling was introduced to catch small cisc
or "bloaters" (nearly all *hoyi*), the fisherm
kept separate records of larger chubs, sold
human food, and bloaters (used mostly
animal food). Bloaters made up 92.5 perc
of the catch in 1960 and 1961 and 95.5 p
cent of the catch in 1962. The percentage
bloaters in trawl catches in 1960–61 is alm
the same as the 92.6 percent of *hoyi* in
perimental gill nets fished in central
southern Lake Michigan (where all trawl
for ciscoes was done) in the same years.
increase to 95.5 percent of bloaters in tr
catches in 1962 may reflect a further adva
in dominance of *hoyi* in the population.
assumption of a continued increase in *h*
also is supported by incomplete analysis
data from experimental trawling by resea
vessels in 1962 and 1963.

LENGTH COMPOSITION

The reduction in the size of gill net m
during the early cisco fishery suggests a
cline in size of the fish in the stocks.
further decline following 1930–32 is sh
by catches of 2½-, 2⅝-, and 2¾-inch mesh
nets (meshes fished at all locations in
periods) in 1954–55 and 1960–61 (Table

ince ciscoes are characteristically larger in he northern end of Lake Michigan than in he central and southern part, they are treated eparately.

The forces selecting against large ciscoes aused a decline in the size of all species, ncluding *hoyi*, following 1930–32. The abence of ciscoes larger than 13.4 inches in 1954–55 and 1960–61 (Table 4) resulted from he elimination of the large individuals of the arious species, and the reduction in average ength of fish in the stock reflects the general eduction of the size of each species. In fact, he average size of *hoyi* in northern Lake Michigan (10.7 inches) in 1932 (Jobes, 1949a) exceeded the average for all species or the northern area (9.3 and 9.5 inches) in 1954–55 and 1960–61 (Table 4).

Although the average length of ciscoes declined 2.1 inches in northern and 1.6 inches n central and southern waters between 1930–32 and 1954–55, subsequent changes in pecies composition were not accompanied by major changes in length (Table 4). In fact, he mean length in the north increased from 9.3 to 9.5 inches between 1954–55 and 1960–61, but the mean length in the central nd south remained unchanged at 8.7 inches.

The catches in the smallest mesh of the xperimental nets (2⅜ inches) might give more accurate information on changes in ength of fish in the population—particularly n the 1950's and 1960's. The 2⅜-inch mesh was the only net fished that gilled *hoyi* effecively. Typically, the size of *hoyi* decreases as the mesh size increases above 2⅜ inches; he smaller *hoyi* are taken in the larger meshes by entanglement whereas the larger individuals are able to pass through larger meshes or free themselves from entanglement (Jobes, 1949a). Thus, the 2⅜-inch mesh might sample a population dominated by *hoyi* more effectively than larger meshes. There was, in fact, little difference between the average lengths of ciscoes taken in the central and southern area in 2⅜-inch mesh (10.2 inches) and larger meshes (10.3 inches) in 1930–32, but the smaller mesh took considerably larger fish in most areas in 1954–55 and 1960–61 (Table 5).

The length of ciscoes taken in the 2⅜-inch mesh varied less among the different areas of the lake due to its greater selectivity than in the catch in larger meshes (Table 5). The suggestion of Moffett (1957) that a cisco population dominated by *hoyi* might be harvested more effectively by nets of 2⅜-inch mesh than by nets of larger meshes is still valid. In fact, as the *hoyi* population increased, the smaller mesh net not only took higher percentages of larger ciscoes than did larger meshes, but also caught substantially greater numbers (Table 6). Ciscoes 9 inches and longer are now sold for human consumption—the only market that brings prices that can sustain a gill net fishery. In 1960–61 the number of ciscoes 9 inches and larger taken in 2⅜-inch mesh was 2.4 to 4.4 times greater than the number taken in larger meshes (ratios at right in Table 6). The ratio of large to small ciscoes in 2⅜-inch mesh in 1960–61 was 3 to 1 compared with the ratio for larger mesh of 1 to 1, and the average number of fish less than 9 inches was

ABLE 5.—*Average lengths of ciscoes taken in Lake Michigan in experimental gill nets of identical specifications in 1930–32, 1954–55, and 1960–61*

Location	Depth (fathoms)	Average total length (inches) of ciscoes caught in					
		2⅜-inch mesh			2½-, 2⅝-, and 2¾-inch mesh		
		1930–32	1954–55	1960–61	1930–32	1954–55	1960–61
orth							
Manistique	50	—	9.5	9.6	11.2	9.1	9.7
Island area	50	—	9.7	9.7	11.6	9.4	9.6
Charlevoix	50	—	9.8	9.5	11.4	9.2	9.3
entral and south							
Ludington	25	10.2	9.5	9.6	9.9	8.6	9.2
Ludington	60	10.1	9.3	8.8	10.1	8.9	8.4
Grand Haven	25	10.4	9.4	9.3	10.5	8.5	8.4
Grand Haven	50	10.1	9.2	9.3	10.7	8.7	8.6
Average							
North		—	9.7	9.6	11.4	9.3	9.5
Central and south		10.2	9.4	9.3	10.3	8.7	8.7
All data		10.2	9.5	9.4	10.8	8.9	9.0

Table 6.—*Number of small and large ciscoes per 1,000 feet of small- and large-mesh gill nets in 1960–61*

Location	Small mesh (2⅜ inches)		Large mesh (2½, 2⅝, 2¾ inches)		Ratio of large fish in small and large mesh
	<9 inches	>8.9 inches	<9 inches	>8.9 inches	
Manistique	64	259	28	110	2.4
Island area	92	415	35	129	3.2
Charlevoix	46	363	53	82	4.4
Ludington	54	245	60	69	3.6
Ludington	118	63	83	20	3.2
Grand Haven	116	196	119	45	4.4
Grand Haven	100	180	124	47	3.8
Average	84	251	71	71	3.5

about the same for both small- and large-mesh nets.

BIOLOGICAL CONSEQUENCES OF POPULATION CHANGE

The lack of information on genetics, behavior, and life-history details makes it necessary to depend largely on speculation in discussing the probable influence of the extreme imbalance of the cisco stock on the biology of the various species that make up the population. Speculation may be instructive, however, as some biologically significant events have been observed.

Difficult as identification of certain individual ciscoes to species always has been in the field, this identification has become even more troublesome in recent years—even for the most experienced investigators. Increasing numbers have been taken during and subsequent to the 1960–61 survey that have almost defied placement with certainty into established species. The same "new fish" have also been noted by the commercial fishermen, who sometimes refer to them as "hybrid chubs." These fish have occasionally dominated an entire catch of both experimental and commercial nets. Most of the difficult-to-identify ciscoes bear a strong resemblance to *hoyi* and have been identified as such. They differ from *hoyi* most in the possession of a more robust appearance—quite unlike the usual thin-bodied *hoyi*. Others of the "new" ciscoes resemble *artedi*, and differ from typical *artedi* in that they are more robust and have a broader, deeper body than the usual *artedi* of deep water. They were recorded as "*artedi* ?" and are responsible for the increase in the number of *artedi* taken in the 1960–61 survey (Table 1). Minor differences in morphological measurements and counts are irregula and do not illustrate clearly the nature an direction of the changes in these forms. Bot new forms show complete gradation into th typical appearance of the species they resemble; thus it was not possible to separate then and treat them as special groups.

A possible explanation for the increasin difficulties in identification and the appearance of "new fish" is that some measure o hybridization has been occurring. *Artedi* an *hoyi* have been artificially crossed successfully,[5] and crosses have been made amon ciscoes, whitefish, and round whitefish (Garside and Christie, 1962; Gasowska, 1956 Gorbunova, 1962). In fact, Svärdson (1957 advocated introgressive hybridization as primary factor in the evolution of Europea whitefishes.

The extreme abundance of *hoyi* in Lak Michigan and the scarcity of other specie have created favorable conditions for hybridization. Differences in spawning time an location once served to keep species separat but these barriers may no longer be effective *Hoyi* is now abundant in all sections an depths of the lake, and although each specie has had its characteristic spawning time, som individuals become ripe at other times of th year. Thus, *hoyi*, in spawning condition, ma have been present at the time and place tha other species spawn. In view of their grea abundance, *hoyi* may have been well repr sented in relation to the number of spawnin individuals of other species. Indeed, the "e tinction" of the last few *johannae* and *nigr pinnis* may have come through introgressiv hybridization for lack of their own speci with which to spawn.

Greatly modified species composition, abu dance, distribution, and possibly other env ronmental shifts may also have modified t morphological characteristics of the cisco of Lake Michigan. Coregonids are noted f their morphological and biological sensitivi to environmental change (Hile, 1937; Svä son, 1950, 1951, 1952, 1953). The remark by Lake Michigan fishermen that there are "many kinds of chubs" now where there were few previously provides evidence of the diversity of morphological change. Observations of large numbers of *reighardi* in spawning condition in the fall in an area where they had spawned the previous spring (their normal spawning time) illustrate a biological change and one that might well increase the probability of hybridization.

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[5] *Artedi* and *hoyi* have been crossed and reared maturity (but have not yet spawned) in devel mental morphology studies of coregonids at the U. Bureau of Commercial Fisheries station at Nor ville, Michigan.

Thus it appears that changes in the morphology and biology of Lake Michigan ciscoes may have resulted from genetic shift and/or from radically modified environment, and that the two effects may not be easily separable. Especially important is the possibility that a nongenetic change in the biology can further the development of genetic change through introgression.

Cursory examination of data from trawl catches in southern Lake Michigan show that *hoyi* dominated the population even more in 1963 than in the same area in 1960. Species other than *hoyi* were extremely scarce in 1963, and difficult to identify with certainty. Several years will pass before the sea lamprey, which preys on large ciscoes, is brought under control, and the lake trout and burbot, which prey on small ciscoes, become abundant again. The trawl fishery for small ciscoes is expanding, but it is questionable whether it will reduce *hoyi* enough to diminish or end the apparent introgressive process which seems to be so far advanced. Indeed, it is not unlikely the form or forms that will constitute future cisco stocks of Lake Michigan will be different than the species recognized in the past.

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20. A NEW LOOK AT AN OLD OCEAN

The sea has from very early times been a source of fascination and perhaps despair to those interested in puzzling out its mysteries.

Scientific oceanography dates from the work of Maury, *circa* 1835, who published the first charts of winds and currents based on compilations of detailed records. His charts of average conditions formed the philosophical basis for modern oceanographic studies.

The study of marine communities began in about 1835 by Forbes, who established the modern discipline of marine biology by making extensive surveys and analyses of systematically collected specimens. The studies of average oceanic properties and the taxonomy and biogeography of marine communities can hardly be said to be complete. For very large parts of the ocean we know little or nothing of its properties, much less its inhabitants.

But important philosophical changes in our approaches to the oceans are taking place, in that there is a growing recognition of the importance placed by cyclical events which repeatedly occur in physical properties and biological communities. Intuitively, we know these events to depend on the influence of our nearest star, whose life-giving light is converted into biological energy and whose heat is moderated and distributed by the thin film of water which covers such a large part of our planet. In order to relate time sequence changes back to the primary energy sources, our attention is turning from descriptions of properties to a descriptive analysis of changes in individual properties and the effects of a change in one part of the system on other parts of the system.

Such an approach has led us to describe our work in general terms as a study of the animal in its environment, and needing to focus on some of the many animal communities, we have chosen the tunas and their associated companions.

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SALINITY, TEMPERATURE, AND FOOD REQUIREMENTS OF SOFT-SHELL CLAM LARVAE IN LABORATORY CULTURE

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SALINITY, TEMPERATURE, AND FOOD REQUIREMENTS OF SOFT-SHELL CLAM LARVAE IN LABORATORY CULTURE

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Abstract. A series of experiments was undertaken to determine (1) suitable methods for spawning and rearing *Mya arenaria* in the laboratory, and (2) some of the basic environmental requirements of *Mya* eggs and larvae.

Adult *Mya* did not respond readily to stimuli commonly used to induce laboratory spawning of marine invertebrates and a new technique was developed to provide viable gametes. This technique consisted of cyclic fluctuations in the temperature of the running water in which the ripe clams were held.

Larvae were reared through metamorphosis and their tolerance to various levels of temperature and salinity were determined. The optimum temperature range was between about 17° and 23°C, although slow development took place as low as 10°C. Optimum salinity was from about $16\ ^0/_{00}$ to $32\ ^0/_{00}$ (the highest value tested). Some differences in response to temperature and salinity between larvae from parents of different origins were observed.

Several species of unicellular algae were tested as larval food. Although *Cyclotella nana* produced the best growth, the larvae grew nearly as well on *Dicrateria inornata* and *Phaeodactylum tricornutum*. The last named species was considered most satisfactory, because in addition to promoting good growth, it was most easily raised in culture.

INTRODUCTION

In recent years laboratory rearing of shellfish larvae has assumed increasing importance, both scientific and practical, and its many potentialities are clearly presented by Loosanoff (1954). The biology of larval molluscs of several species, especially *Mercenaria mercenaria* and *Crassostrea virginica,* has been studied extensively, and commercial applications of these studies have been in operation for several years. Although similar work with the soft-shell clam (*Mya arenaria*) has been undertaken in a limited way by several investigators (Mead and Barnes 1904; Belding 1931; Loosanoff 1954), no detailed accounts of culture methods, growth rates, food requirements, or other biological information are available for the larval stages.

The Bureau of Commercial Fisheries Biological Laboratory at Boothbay Harbor, Maine, has been engaged in research on the biology of *Mya*. One of the objectives has been to study methods of spawning and rearing *Mya* larvae and to determine some of their ecological requirements. This information is needed not only for producing large numbers of clams of known age and background for experimental work, but also to provide a basis for interpreting observations on natural clam populations. This paper describes the techniques which have proved successful in spawning and rearing eggs and larvae and discusses the effects of variations in some environmental factors as determined in laboratory experiments.

Methods

OBTAINING RIPE GAMETES

Essential to practical larval culture is the procurement of ripe gametes in sufficient quantity. Two general methods are available: (1) stripping, or excising parts of the ripe gonad and teasing out the eggs or sperm into clean water; and (2) inducing the animals to spawn under conditions convenient for collecting the gametes. The latter is the only satisfactory method with *Mya*. Both Belding (1931) and Mead and Barnes (1904) reported poor viability in *Mya* eggs obtained by stripping, and I found that the eggs invariably ruptured and disintegrated immediately on being freed from the ovaries. Sperm of apparently normal potency can, however, be stripped from the male gonad.

A wide variety of techniques to induce spawning in marine invertebrates has been described in the literature, including thermal, mechanical, and electrical shock, treatment with chemical agents, and treatment with naturally occurring organic substances such as hormones, sperm, or plant extracts. Costello *et al.* (1957) summarized many of these methods in a convenient laboratory manual. Loosanoff (1954) used successfully a combination of thermal and chemical stimulation on many species of bivalve molluscs. The animals were held in containers of sea water immersed in a water bath, the temperature of which was raised rapidly while small quantities of sperm stripped from males was introduced into the containers. The sperm apparently contains stimulatory agents which elicit the spawning response in both sexes. In *Mya*, however, I was unable to bring about spawning by this technique, even after several hours and repeated applications of the stimuli. Electrical stimuli, manipulations of pH, salinity, and dissolved oxygen, and treatments with estrogenic hormones were similarly unsuccessful.

A modification of the thermal stimulation technique did, however, produce satisfactory results. Groups of 20 to 100 ripe clams were held in polyethylene or fiberglas trays through which sea water flowed at a rate of about 20 liters per hr. The water supply was heated intermittently by an immersion heater connected to a timing device. This arrangement provided a cycle of alternate warming and cooling periods (i.e., to seasonal water temperature) which over an extended time would stimulate an "epidemic" spawning among the clams. Although the heating cycle generally used was 6-hr-on-6-hr-off schedule, a 6-hr-on-18-hr-off cycle was also successful, and occasionally spawning followed a single warming phase. In most cases spawning occurred at night, and when a single 6-hr warming phase per day was used, spawning took place only when this warming was programmed to occur at night. The range of temperature fluctuation varied, depending on the rate of water flow and the seasonal water temperature. An elevation of from 5 to 10°C above seasonal normal generally brought about spawning. During the course of the experiments the seasonal water temperature varied between 7 and 13°C.

There are 2 advantages of this method of stimulation which might account for its success. The stimuli are applied automatically for extended periods of time, and there is a continuous exchange of water preventing the accumulation of metabolites during the relatively long refractory periods characteristic of the species. The inhibitory effect of these metabolites is indicated by the fact that a complete change of water is often followed by spawning, not only with *Mya* in the system described, but with other species in standing water.

Mya was also induced to spawn by injecting about one ml of 0.1 N ammonium hydroxide into the gonad through the mantle strap. One effect of this reagent is to cause the breakdown of the egg nucleus (germinal vesicle) and the initiation of meiosis. This technique produced relatively small numbers of eggs, probably because only those eggs near the site of penetration were shed. Ordinarily, a single female released one to 5 million eggs at one spawning, but artificially stimulated with ammonium hydroxide, a single individual produced fewer than 100,000. Moreover, the toxic effect of the ammonia on the clam soon killed it. Nevertheless, the eggs obtained by this method were viable and, after fertilization, developed into normal larvae.

Spawning was most successful when the breeding stock was at the peak of ripeness and well nourished. Ripe clams were obtained from various sources depending on the season of the year and the characteristics of the reproductive cycle. In early spring, clams from Woods Hole, Massachusetts, were found most satisfactory.

Local clams from Maine were used during June and early July, and in the fall, ripe clams were obtained from Chesapeake Bay. The latter, indigenous to water of relatively low salinity (about 10 to 15 ‰), had to be gradually acclimatized to the salinity of Maine coastal water (about 32 ‰) for a period of several days, or they would not survive the change. Even after an acclimatization period of 2 weeks, although the clams appeared to be functioning normally, they would not respond to spawning stimuli unless the salinity was again reduced to about 20 ‰. When such reduction was necessary, a recirculating water supply, diluted with either demineralized tap water or pond water, gave satisfactory results.

PREPARATION OF EXPERIMENTAL CULTURES

The methods of handling eggs and larvae were adapted from those developed by Loosanoff and Davis (1950), Loosanoff, Davis, and Chanley (1953), Loosanoff (1954), and Davis (1958). Eggs were incubated and larvae reared in containers of filtered sea water which had passed through an ultraviolet irradiation cell to reduce the bacterial flora. For experimental work, 1,500-ml glass beakers were used as culture jars; mass cultures of eggs and larvae were held in polyethylene tanks of various sizes. Water was ordinarily changed every 2d or 3d day by straining the old water through a stainless steel sieve with a nominal mesh opening of 50 μ, then rinsing the larvae thus collected back into clean irradiated sea water.

Because it is essential to limit the number of eggs or larvae per unit volume of culture water, estimates were made of the numbers allotted to each culture jar. Masses of fertilized eggs were siphoned from the bottom of the spawning tray into a clean container through a sieve with a nominal mesh opening of 100 μ. This removed larger particles of debris. An aliquot part of this egg suspension was removed for counting under a microscope. After the number of individuals per ml had been determined, appropriate volumes of the egg suspension were transferred by pipette to culture jars of filtered and irradiated sea water. The density of eggs in these cultures was limited to less than 50,000 per liter. To obtain larvae for experimental cultures, eggs were first incubated in larger containers. After 48 hr, when the eggs had developed into straight-hinge veligers, these larvae were concentrated into a relatively small volume of water; an aliquot part was counted to determine the density; and appropriate volumes were pipetted in culture jars. The density of larvae in these cultures was limited to less than 10,000 per liter.

FEEDING

As the larvae were held in filtered standing water, they had to be fed supplementally by the addition of small quantities of unicellular algae after each water change. The amount added was sufficient to give a concentration in the culture of about 100,000 cells per liter. The species of algae used are of some importance and will be discussed subsequently.

The algae were grown in 10- and 20-liter Pyrex carboys on an inorganic culture medium described by Davis and Guillard (1958). Upon attaining useful cell concentrations, the algal suspensions were drawn off as needed. Equal rations were provided the larvae simply by pipetting equal volumes of a stock suspension into the culture jars. In experiments where equivalent quantities of different algal species were required (as, for instance, in comparing relative food values of the different algae), the rations were equalized on the basis of the cell concentration and dry weight. Cell concentrations were determined by counting samples of the algal suspension with a haemocytometer. Dry weight values were obtained by filtering measured volumes of known cell concentration through tared millipore filters. Each dry weight value was the mean of 8 to 10 samples. The filters with the accumulated cells were dried to constant weight and weighed on an analytical balance. Larval cultures were provided with appropriate volumes of algal suspensions to give an equal biomass of food to each culture.

HYGIENE

One of the greatest difficulties encountered in rearing larvae was bacterial contamination. Large numbers of bacteria were necessarily introduced into cultures together with the eggs collected from the spawning trays. However, if stock egg suspensions could be collected in sufficient density, the relatively small volumes of contaminated water accompanying the desired number of eggs was diluted to harmless levels in the culture jars. It was necessary to collect the eggs as soon after spawning as possible, since the masses of eggs, mucus, blood and tissue cells, and debris in the trays provided an ideal substrate for bacteria. Heavily contaminated egg cultures suffered high mortality, and the dead and disintegrating eggs promoted further bacterial growth.

The use of antibiotics was highly satisfactory in reducing bacterial contamination. A combination of penicillin G and streptomycin sulfate proved

100% effective in preventing bacterial multiplication in sea water. Added to egg cultures at the rate of 100 mg of streptomycin and 50,000 units of penicillin per liter of water, this combination showed no adverse effect on egg development.

In some cases, it was necessary to continue the use of antibiotics in larval cultures, but usually the initial treatment of eggs kept subsequent larval cultures relatively clean.

All glassware and utensils were washed with a laboratory detergent and rinsed in hot water, and precautions were taken to keep all operations as aseptic as possible. Contact of copper or copper alloys with all water used in cultures was avoided, for this metal is extremely toxic. Because these and other metallic ions are often present in tap water, dilutions for salinity tolerance experiments were made by passing tap water through an ion-exchange column. Tap water demineralized in this way has been found to be nontoxic to larvae and entirely satisfactory for diluting sea water (Davis 1958).

EXPERIMENTAL PROCEDURE

Estimates of larval survival and growth were made by sampling 2% of the population in each culture, every 2d or 4th day. The culture was concentrated to a volume of 200 cc by collecting the larvae in a sieve and washing them into a graduated cylinder. The cylinder was agitated to insure homogeneity, and a 4 cc sample was removed with an automatic pipette. The number of larvae in these samples was counted under the microscope in a Sedgewick-Rafter counting cell. The mean size of the larvae was determined by measuring with an ocular micrometer the first 50 individuals encountered in scanning the cell. Although these measurements were made to the nearest micron, this had to be interpolated from a scale marked in 5 µ intervals. Therefore the precision of the data is somewhat less than the computed figures might indicate.

Three environmental variables were tested: temperature, salinity, and food. The effects of temperature and salinity were tested independently and on eggs and larvae separately. In addition, these variables were tested on larvae from parents of several origins. The continuous low salinity of upper Chesapeake Bay as contrasted to the variable but predominantly high salinity of the New England coast suggested possible differences in salinity tolerances of the larvae from these 2 regions. Unfortunately, however, it was not possible to conduct simultaneous experiments on these 2 populations because of the difference in spawning season. Effects of salinity were tested at room temperature (18 to 20°C) and those of temperature tested at the prevailing local salinity (31 to 32 ⁰/₀₀). The criteria for assessing these effects were the growth (increase in mean shell length) of the larvae and the percentage of egg survival after 48 hr of incubation.

Because all experiments were not conducted at the same time, it was not always possible to provide the same type of food. Mass cultures of several algal species were maintained routinely, but only those mature cultures which had reached high cell concentrations at the time clam larvae were being produced were suitable.

RESULTS

Effect of salinity on the development of Chesapeake Bay eggs

Duplicate one-liter cultures of about 26,600 recently fertilized eggs each were incubated at salinities of 32, 16, and 10 ⁰/₀₀, representing the general categories of high, intermediate, and low salinity. After 48 hr the cultures were sampled. The percentage of the initial population transformed into straight-hinge veligers and also the percentage of living larvae of all stages were determined from a 2% aliquot (Table I). The total survival was about the same at all salinities, but the transformation to shelled veligers was somewhat better at the intermediate salinity.

TABLE I. Survival of Chesapeake *Mya* eggs incubated 48 hr at different salinities

Salinity 0/00	No. of eggs	Per cent survival	Per cent straight hinge veligers
32	26,600	73	14
32	26,600	70	13
16	26,600	70	16
16	26,600	68	23
10	26,600	85	2
10	26,600	57	3

Effect of salinity on growth of Chesapeake Bay larvae

The straight-hinge larvae from eggs incubated 48 hr at 20°C and 20 ⁰/₀₀ salinity (approximate conditions at spawning) were distributed into 6 one-liter cultures of about 8,000 larvae each. Two of these cultures were at a salinity of 32 ⁰/₀₀, 2 at 16 ⁰/₀₀, and 2 at 10 ⁰/₀₀. All were held at room temperature of 18 to 20°C and fed equal rations by volume from a single large culture of *Monochrysis lutheri*. The cultures were sampled every 4th day, and the mean size of the larvae computed.

TABLE II. Growth of Chesapeake Bay *Mya* larvae at different salinities

Salinity 0/00	Mean size (in μ) at age			
	2 days	4 days	8 days	12 days
32	105	114.3	143.0	167.0
32	105	114.0	144.2	161.4
16	105	113.8	158.1	167.4
16	105	116.5	148.0	173.2
10	105	109.5	136.3	151.5
10	105	109.2	146.1	159.5

Table II shows the increase in mean size during a period of 12 days. Although substantial growth took place at all salinities, the best occurred at the intermediate salinity. Mortality was light in all cultures except those at 32 $^{0}/_{00}$ in which many larvae died during the last few days of the experiment. Metamorphosis had begun in all but the 10 $^{0}/_{00}$ cultures by the 12th day.

Effect of temperature on growth of Chesapeake Bay larvae

Three pairs of one-liter cultures, each containing about 3,000 straight-hinge larvae, were held at mean temperatures of 11, 14, and 24°C. Each temperature varied about ± 1°C from the mean. The cultures were fed equal quantities by volume of *Monochrysis* and were sampled every 4th day. The growth data are shown in Table III. Although the larvae at 14° grew much more slowly than those at 24°, mortality was slight, whereas at 11° mortality was high and in one case, total.

TABLE III. Growth of Chesapeake Bay *Mya* larvae at different temperatures

Mean temperature °C	Mean size (in μ) at age				
	2 days	6 days	10 days	14 days	18 days
24	105	118.2	178.3	193.3	All metamorphosed
24	105	126.5	180.5	200.5	All metamorphosed
14	105	107.6	128.7	138.2	137.4
14	105	108.8	141.1	137.1	142.9
11	105	104.6	126.7	125.9	126.3
11	105	106.9	116.4	130.7	All dead

Effect of salinity on the development of New England eggs

Two groups of eggs were used in 2 separate experiments. In the first, eggs from Woods Hole clams were incubated 48 hr in duplicate one-liter cultures, each containing about 27,600 eggs, at salinities of 32, 22, 16, and 11 $^{0}/_{00}$. In the 2d, eggs from Maine clams were incubated 48 hr in duplicate one-liter cultures of about 36,000 eggs each at salinities of 31, 23, 16, and 8 $^{0}/_{00}$. Percentages of total survival and of transformation to straight-hinge veligers were computed from 2% aliquot samples. The measured salinity values in the 2 experiments differed slightly owing to variations in the original salinity of the sea water used and the amount of water added with the eggs. These values are assumed to be sufficiently close, however, to represent high, intermediate, and low salinity levels and to be comparable on that basis. The survival data are given in Table IV.

TABLE IV. Survival of New England *Mya* eggs incubated 48 hr at different salinities

Salinity 0/00	No. of eggs	Per cent survival	Per cent straight hinge veligers
WOODS HOLE, MASS., EGGS			
32	27,600	43	35
32	27,600	42	33
22	27,600	43	28
22	27,600	49	34
16	27,600	34	12
16	27,600	34	13
11	27,600	0	0
11	27,600	0	0
BOOTHBAY HARBOR, MAINE, EGGS			
31	36,000	85	77
31	36,000	93	81
23	36,000	99	79
23	36,000	98	82
16	36,000	58	3
16	36,000	65	5
8	36,000	4	1
8	36,000	6	1

In both cases, survival and development were best at the higher salinities, dropping off rapidly below about 20 $^{0}/_{00}$. This is quite unlike the situation with Chesapeake Bay clams, which survived better at intermediate salinity.

Effect of temperature on development of New England eggs

The eggs used were from Woods Hole parents. Duplicate one-liter cultures of about 25,000 eggs each were incubated at mean temperatures of 8.5, 15, 22.5, and 28°C. These temperatures varied not more than ± 1°C. The cultures were sampled at 18 hr and again at 48 hr after fertilization. Percentages of total survival (living larvae at any stage of development) and of development to the

Table V. Survival of New England *Mya* eggs at different temperatures after incubation of 18 and 48 hr

Temperature °C	No. of eggs	18 hours: Per cent survival	18 hours: Per cent straight hinge veligers	48 hours: Per cent survival	48 hours: Per cent straight hinge veligers
28	25,000	52	2	23	9
28	25,000	46	0	17	10
22.5	25,000	78	44	34	28
22.5	25,000	72	44	46	46
18	25,000	62	0	89	89
18	25,000	96	0	97	90
15	25,000	76	0	72	71
15	25,000	74	0	66	66
8.5	25,000	68	0	26	0
8.5	25,000	66	0	45	0
4.5	32,000	—	—	31	0
4.5	32,000	—	—	27	3

straight-hinge veliger stage were computed. The data are given in Table V, which also includes the results of a separate experiment with another pair of cultures containing about 32,000 eggs and incubated at 4.5°C.

At 22.5°C, many eggs had reached the straight-hinge state in 18 hr. After 48 hr, substantial numbers had reached this stage at all temperatures from 15 to 22.5°C, with the greatest percentage at 18°C. The eggs which had developed most rapidly (at 22.5°) had a noticeably higher mortality than those which developed more slowly at 15 and 18°. High mortality and poor development took place at 8°C and lower and at 28°C.

Effect of salinity on the growth of New England larvae

These larvae were from Woods Hole parents. Duplicate one-liter cultures of about 7,600 straight-hinge larvae each were held at salinities of 32, 21, 16, and 10 $^0/_{00}$. The larvae were fed equal quantities from a single large culture of *Dicrateria inornata.* Samples were taken at 4-day intervals. Growth data are shown in Table VI. Mortality was light and about the same at all salinities. Pronounced differences in growth at the different salinities were not apparent, but growth was definitely better at the higher salinities.

Table VI. Growth of New England *Mya* larvae at different salinities

Salinity 0/00	Mean size (in µ) at age: 2 days	5 days	9 days	13 days
32	107	125.6	157.1	186.0
32	107	129.8	156.7	180.5
21	107	121.7	154.1	166.7
21	107	118.4	148.8	173.0
16	107	119.3	145.9	170.3
16	107	124.5	148.4	174.8
10	107	112.4	128.4	160.0
10	107	110.5	131.6	159.9

Effect of temperature on the growth of New England larvae

The larvae in this experiment were from Maine parents. Five pairs of one-liter cultures, each containing about 6,000 straight-hinge larvae, were held at mean temperatures of 8.6, 14.6, 18.6, 22.9, and 28.4°C. These temperatures varied not more than ± 1.5°C. The cultures were sampled every 4 days for a 12-day period, with the exception of one culture at 8.6°C which was held an additional 11 days. All were fed equal quantities from a single culture of *Phaeodactylum tricornutum.* The rate of growth increased with temperature up to about 23°, but was adversely affected at 28°C (Table VII). Whether the lethal effect at 28° was due to temperature alone or other causes associated with high temperature could not be determined.

Table VII. Growth of New England *Mya* larvae at different temperatures

Mean temperature °C	Mean size (in µ) at age: 2 days	6 days	10 days	14 days	25 days
28.4	110.4	144.0	167.7	Dead	
28.4	110.4	141.7	164.6	Dead	
22.9	110.4	131.3	172.1	195.6	
22.9	110.4	133.2	173.1	196.8	
18.6	110.4	144.6	172.4	189.8	
18.6	110.4	142.8	171.8	198.4	
14.6	110.4	121.9	151.7	168.7	
14.6	110.4	127.4	158.0	173.9	
8.6	110.4	113.7	118.8	—	—
8.6	110.4	114.0	121.8	133.8	165.6

FOOD VALUE OF VARIOUS UNICELLULAR ALGAE

The relative value of several species of unicellular algae as food for oyster and hard-clam larvae has been discussed by Davis and Guillard (1958). Several of these species have proved to be satisfactory foods for *Mya* larvae. To test the relative values of these and other species more precisely, the following experiment was conducted.

Five pairs of one-liter cultures, each containing about 7,000 straight-hinge veligers, were fed every other day. Each of the 5 pairs was ed a different algal species. The quantities supplied were equated with one another on the basis of cell counts and dry weights as described earlier. The cultures were held at 20°C and 32 $^0/_{00}$ salinity and sampled for growth measurements every 4th day.

The algal species provided were *Dicrateria inornata*, *Phaeodactylum tricornutum*, *Monochrysis utheri*, *Dunaliella* sp., and *Thalassiosira fluviatilis*. A 6th pair of unfed cultures was used as a control. A separate experiment was conducted to compare a 6th algal species, *Cyclotella nana*, with *Phaeodactylum* and another unfed control. The results of these experiments are shown in Table VIII. All foods promoted some growth, although *Thalassiosira* appeared to be toxic, or at least to have toxic contaminants. The best growth occurred in cultures fed *Cyclotella*, followed by *Phaeodactylum*, *Dicrateria*, *Monochrysis*, and *Dunaliella*.

TABLE VIII. Comparative growth of *Mya* larvae fed different species of unicellular algae

Food	Mean size (in μ) at age			
	2 days	5 days	9 days	13 days
Unfed control	107	113.6	119.4	128.9
Unfed control	107	111.8	117.7	131.2
Thalassiosira	107	110.9	117.0	140.2
Thalassiosira	107	110.2	115.4	123.0
Dunaliella	107	121.4	145.5	183.7
Dunaliella	107	121.9	142.3	160.3
Monochrysis	107	120.7	141.6	177.1
Monochrysis	107	118.7	145.0	176.8
Dicrateria	107	125.6	157.1	186.0
Dicrateria	107	129.8	156.7	180.5
Phaeodactylum	107	123.6	159.4	201.8
Phaeodactylum	107	133.3	163.8	195.9
	2 days	6 days	10 days	14 days
Unfed control	110	124.2	127.2	136.1
Cyclotella	110	144.5	178.0	[a]
Cyclotella	110	145.4	[a]	201.5
Phaeodactylum	110	142.8	171.8	198.4
Phaeodactylum	110	144.6	172.4	189.8

[a] Sample accidentally lost.

DISCUSSION AND CONCLUSIONS

Although *Mya arenaria* is essentially a cold water species (its range extends into Arctic regions), larval development progressed most rapidly at intermediate temperatures. Since the species is estuarine and neritic in habitat, it is not surprising that the larvae have a broad tolerance to both temperature and salinity. The optimum temperature range is a few degrees above and below 20°C, although development takes place slowly even below 10°C.

Under ideal conditions, the larval life of the fastest growing individuals is about 12 days from the time of spawning. Metamorphosis usually does not occur until the larvae reach a size of 200 μ, although a few individuals were found which had metamorphosed at as small a size as 180 μ. Larvae held at low temperatures did not metamorphose during the course of the experiments, but their size at 3 weeks (see Table VII) suggested that larval life at less than 10°C would exceed one month.

As larvae grow, the variation in sizes of a single age group under identical conditions increases markedly. Although the first individuals start to metamorphose after 12 or 13 days, many remain pelagic for several weeks. It is therefore difficult to define a developmental rate for a particular set of conditions. However, since metamorphosis usually occurs at sizes above 200 μ, the time required to attain this average length is accepted as a measure of the length of larval life.

Larvae from parents having dissimilar environmental backgrounds showed differences in response to temperature and salinity. For instance, Chesapeake Bay eggs had a high survival (85%) at low salinity whereas the survival of New England eggs at low salinity was negligible. The best development (i.e., attainment of straight-hinge stage) of Chesapeake Bay eggs took place at intermediate salinity, whereas development of New England eggs was best at the highest salinity. Similarly, the larvae of the Chesapeake Bay stock grew most rapidly at the intermediate salinity, whereas the New England larvae grew fastest at high salinity. A wide disparity in over-all survival among the eggs from the 3 parent stocks may be noticed upon examination of Tables I and IV. This should not be regarded as pertinent, since many factors not related to parental origin could vary the over-all survival between any 2 lots of eggs. What should be regarded as pertinent is the relative survival at different salinities within a lot from one stock, as compared with the relative survival at different salinities within a lot from a different stock.

Intraspecific physiological variations between populations from different localities, both genotypic and phenotypic, appear to be not uncommon phenomena and may be of considerable significance. Differences in response or tolerance to temperature or salinity are often persistent and seem in many cases to be compensatory (Bullock 1955; Rao 1953). Rao has shown that California sea mussels from colder latitudes pump water faster at any given temperature than those from warmer latitudes. Whether or not these variations are genotypic or phenotypic is not certain, however.

The fact that the differences in response of the *Mya* larvae described above were observed in individuals which had had no conditioning experience in their native habitat suggests the possibility that their responses might have been inherited. However, the fact should not be overlooked that in the case of salinity, the eggs and early larval stages of the Chesapeake Bay clams had been conditioned for at least 48 hr to water of somewhat lower salinity than the eggs of Maine clams, simply because the Chesapeake adults apparently required this dilution in order to spawn.

Nevertheless, differences in response to temperature could not have been due to similar conditioning since the temperatures for spawning and egg incubation were approximately the same for both groups. At 11°C the Chesapeake Bay larvae grew very slowly and died after 18 days. At 8.6°C the Maine larvae grew about as slowly but were still living at 25 days and had grown substantially (Table VII). Moreover, at 14°C the 14-day growth increment of Chesapeake larvae was less than half what it was at 24°C; the 14-day growth increment of the Maine larvae at 14.6°C was considerably more than half what it was at 23°C. The greatest difference between the growth of the 2 groups was at the intermediate temperature range which was rather low by Chesapeake Bay standards, but about normal for coastal Maine water.

It is perhaps unfortunate that the experiments were conducted at different seasons and with different algal species as foods. However, in relation to the life history of the organism the seasons were the same (i.e., within a few weeks of the time of spawning). Differences in growth due to diet ought to be reflected more or less consistently over the range of temperatures or salinities, whereas the observed growth patterns were quite different at some temperature and salinity levels but very similar at others. These differences in growth are summarized in Figure 1.

The effects of temperature and salinity on larval development have a more direct application to the ecology of the larvae in their natural environment than do the effects of feeding selected species of algae as food. These feeding experiments are in a sense artificial, since the extent to which the species are used in nature is not known. Nevertheless, it is of practical importance for laboratory work (and possible eventual hatchery operations) to provide a suitable diet for experimental animals: suitable not only in promoting good larval

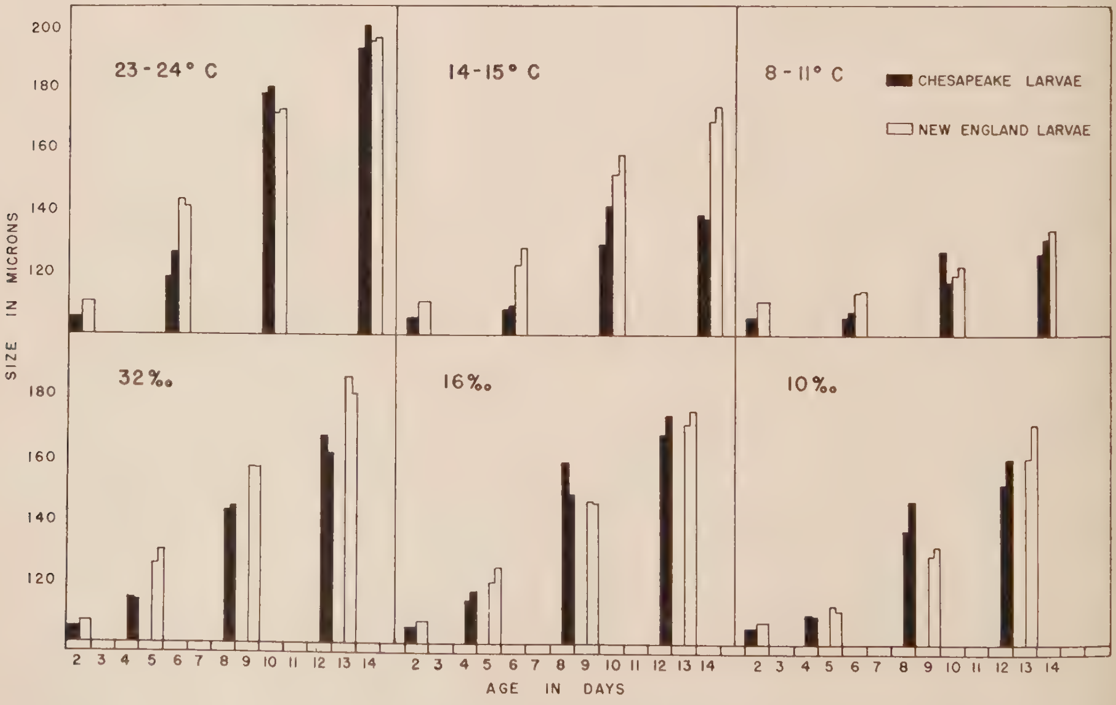

FIG. 1. Comparative growth of *Mya* larvae from Chesapeake Bay and New England parents at various salinities and temperatures.

owth, but also in being conveniently and eco- mically produced. Unfortunately, some of the gae which promote the best larval growth are emselves difficult to grow in culture, and some sily cultured algae are useless as larval food. or example, *Cyclotella*, which produced the best rval growth, was relatively difficult to grow in lture; conversely, *Dunaliella*, which can be own easily and rapidly, is a poorer larval food. *haeodactylum* was nearly as good a food as *yclotella* and almost as readily cultured as *unaliella*; hence it must be considered a more itable food than either of the latter.

Apparently there is no relationship between the xonomic position of the algae and their suitability as food. *Cyclotella* and *Thalassiosira*, re- ectively the best and worst foods tested, are osely related species of diatoms. *Cyclotella*, *haeodactylum*, and *Dicrateria*—all excellent ods—are less closely related taxonomically. The me and effort involved in culturing large quanti- es of unicellular algae indicate the desirability of nding some more easily obtainable or storable aterial as a substitute: e.g., pulverized cereals d milk solids. Carriker (1961) raised the larvae the hard clam (*Mercenaria*) to metamorphosis a filtrate of "Pablum"; however, whether the rvae fed on the material itself or on microorgan- ms using it as a substrate is not clear. More- er, larval mortality was apparently high.

Blegvad (1914) considered organic detritus to a staple item in the diet of many marine organ- ms, and the principal source of this detritus was lgrass (*Zostera*). A few experiments were nducted with *Mya* larvae to test ground and rained *Zostera* leaves as food and also sea lettuce *Ilva*) similarly treated. In neither case did the rvae grow any more than did unfed controls. hether the material was unsuitable as food, or e inhibiting effect of rapid bacterial prolifera- n was responsible cannot be stated, although owth was no better when the larval cultures ere treated with penicillin to reduce the bacterial growth. Bacterial contamination is one of the chief difficulties in using nonliving organic substances as food. Bacteriostatic agents may help retard, but fail to eliminate, this fouling. At the present time, living algal cells of an easily cultured species seem to be the best material for larval food.

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Further Notes on the Identification and Biology of Echeneid Fishes

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TEMPTS TO IDENTIFY several small echeneid es revealed that some of the more useful lt characters are not present in the young. ecifically, disk length, pectoral fin rigidity, dy and fin morphology, and scale size and nber are features which change with growth. tain meristic characters were found to be stant over the 14 to 640-mm length range sidered, and were usable in identifying small cimens. This paper presents a key to the eneidae with further observations on their logy.

The methods employed require only brief cription. The leathery membranes were re- ved from the fins of all but the smallest ividuals in order for the rays to be counted. is was particularly necessary for the dorsal the anterior rays of which are recumbent l would otherwise escape detection. The up- most pectoral ray, a short bony splint, was nted as a ray. Scale examination involved oving a small square of skin from the side ow the rear edge of the disk, staining this are with alizarin, and removing the rubbery dermis. Both lateral line and ordinary scales e then visible in this piece of tissue. No type terial was examined, nor was it possible to specimens of all species. The names used in accordance with Maul (1956).

Table 1 presents the meristic data obtained m specimens in the collection of the Bureau Commercial Fisheries Biological Laboratory Honolulu. These data are the main basis for following key, although supplementary in- mation was used for the species not seen and roaden the range of some characters. This rmation was obtained from the following orts: Bigelow and Schroeder (1953:485–487), Breder (1936:43), Cadenat (1950:265; 1953:674–680), Clemens and Wilby (1949: 329), Clothier (1950:51), Follett and Dempster (1960:172–176), Fowler (1941:269–275), Hildebrand (1946:479), Jordan and Evermann (1898:2268–2273), Krefft (1953:278), Maul (1956), Meek and Hildebrand (1928:896–899), Munro (1955:268), Schultz (1943:258–260), Smith (1950:341–342; 1958:319), and Szidat and Nani (1951:399–407).

The two species of *Remoropsis* recognized by Maul (1956) do not differ meristically, nor are they clearly distinguishable by other means. In general, the body scales of *brachypterus* are large, closely spaced, and superficial, while those of *pallidus* are small, scattered, and embedded. In large *brachypterus,* however, the scales are partially embedded, and, in addition, some *pallidus* have large scales. The shape and spacing of the lateral line scales varies from point to point along the lateral line, and Strasburg (1959: 244) found specimens with the coloration of *pallidus* but the lateral line of *brachypterus.* These facts suggest that *pallidus* and *brachypterus* are very closely related, if not synonymous. In the absence of a definitive monograph, they are retained as distinct species characterized solely by color pattern.

The length of the sucking disk has sometimes been used as a taxonomic character in the Echeneidae (cf Maul, 1956:18). *Rhombochirus* has been distinguished from the other genera, exclusive of *Remilegia,* by the fact that its disk reaches to or past the pectoral tips. The posterior extent of the disk and pectoral fins of echeneids of various lengths is shown in Figure 1. Below 65 mm standard length the pectorals of *Rhombochirus* extend farther posteriorly than the disk, as is always the case with *Remora, Remoropsis,* and *Phtheirichthys.* While this character may be used for large individuals, it

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U. S. Bureau of Commercial Fisheries Biological oratory, Honolulu, Hawaii. Manuscript received ember 26, 1962.

TABLE 1

FREQUENCY DISTRIBUTION OF MERISTIC CHARACTERS IN CENTRAL PACIFIC ECHENEIDAE

CHARACTERS	NO. OF LAMINAE OR FIN RAYS																															
	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
disk laminae, *P. lineatus*	1	7	3																													
R. osteochir									8	36	9	1																				
R. remora									13	15	1																					
R. pallidus							4	7	7	1																						
R. brachypterus								3	3																							
dorsal rays, *P. lineatus*																						1		1	1	2		3	1	1		1
R. osteochir													2	5	13	17	10	6	1													
R. remora														2	4	12	8	3														
R. pallidus																				2	3	4	7		3							
R. brachypterus																				1			4	1								
anal rays, *P. lineatus*																						1			1	2	1	4	2			
R. osteochir													1	13	18	15	5	2														
R. remora														3	19	7																
R. pallidus																	4	7	7	1												
R. brachypterus																	2	2	2													
pectoral rays, *P. lineatus*									1		6	2	1																			
R. osteochir												1	19	27	7																	
R. remora																		8	16	4	1											
R. pallidus																	3	15	1													
R. brachypterus																	2	2	2													

KEY TO THE ECHENEIDAE

Disk laminae 13 or fewer
- 2a. Laminae 9–11, dorsal 30–40, anal 29–38................*Phtheirichthys lineatus* (Menzies)
- 2b. Laminae 12–13, dorsal 16–22, anal 20–26................*Remorina albescens* (Schlegel)

Disk laminae 14 or more
- 3a. Laminae 20–28, usually 21–27
  - 4a. Dorsal 31–42, anal 30–38................*Echeneis naucrates* Linnaeus
  - 4b. Dorsal 20–26, anal 20–26................*Remilegia australis* (Bennett)
- 3b. Laminae 14–20, usually 15–19
  - 5a. Dorsal 21–27 (usually 22–26), laminae 17–20
    - 6a. Pectoral 20–23................*Rhombochirus osteochir* (Cuvier)
    - 6b. Pectoral 26–29................*Remora remora* (Linnaeus)
  - 5b. Dorsal 28–33, laminae 14–18 (usually 15–17)
    - 7a. Caudal black with white corners in specimens 27–164 mm standard length; dorsal and anal black with white edges, white becoming obsolescent with growth................*Remoropsis brachypterus* (Lowe)
    - 7b. All fins uniformly pale colored................*Remoropsis pallidus* (Schlegel)

TABLE 2

Hosts or Habits of Echeneid Fishes

ECHENEID	NO. EXAMINED	STANDARD LENGTH (mm)	HOST OR HABIT
irichthys lineatus	3	32.8–300	free-living
	5	44.0–55.8	long-line buoy or bait
bochirus osteochir	4	14.3–45.7	free-living
	1	51.2	long-line buoy
	1	48.4	*Acanthocybium solandri*
	4	66.7–85.0	*Tetrapturus angustirostris*
	11	49.8–230	*Makaira audax*
	27	38.5–313	*Makaira ampla*
ra remora	7	31.3–77.4	free-living
	2	49.3–87.6	*Carcharhinus melanopterus*
	12	50.9–154	*Pterolamiops longimanus*
	1	222	*Prionace glauca*
	1	640	*Rhincodon typus*
ropsis brachypterus	1	27.1	free-living
	1	80.0	*Makaira audax*
	2	83.7–112	*Makaira ampla*
ropsis pallidus	1	118	free-living
	2	79–83	*Istiophorus orientalis*
	4	116–184	*Makaira audax*
	2	128–152	*Makaira ampla*
	5	128–194	*Istiompax marlina*
eis naucrates	2	50–57 (est.)	*Ostracion lentiginosus* and the author

is clear that *Rhombochirus* shorter than about 65 mm cannot be distinguished from the other genera by the disk length/pectoral length relationship.

Table 2 summarizes the length and host data for the specimens listed in Table 1. Where the host was identified only as "marlin" or "shark" no listing was made in Table 2. Also excluded are three echeneids removed from fish stomachs: a 46-mm *P. lineatus* and a 118-mm *R. pallidus* from *Neothunnus macropterus,* and a 56-m *R. osteochir* from a "swordfish." The term "fre living" denotes echeneids captured by plankt net, midwater trawl, or dipnet beneath a ligh

An aspect of echeneid biology which meri some discussion is the change in habit or ho with growth. As shown by Strasburg (1959 attachment tends to be specific with respect host and attachment site. For example, *Phthe richthys* is either free-swimming or attach

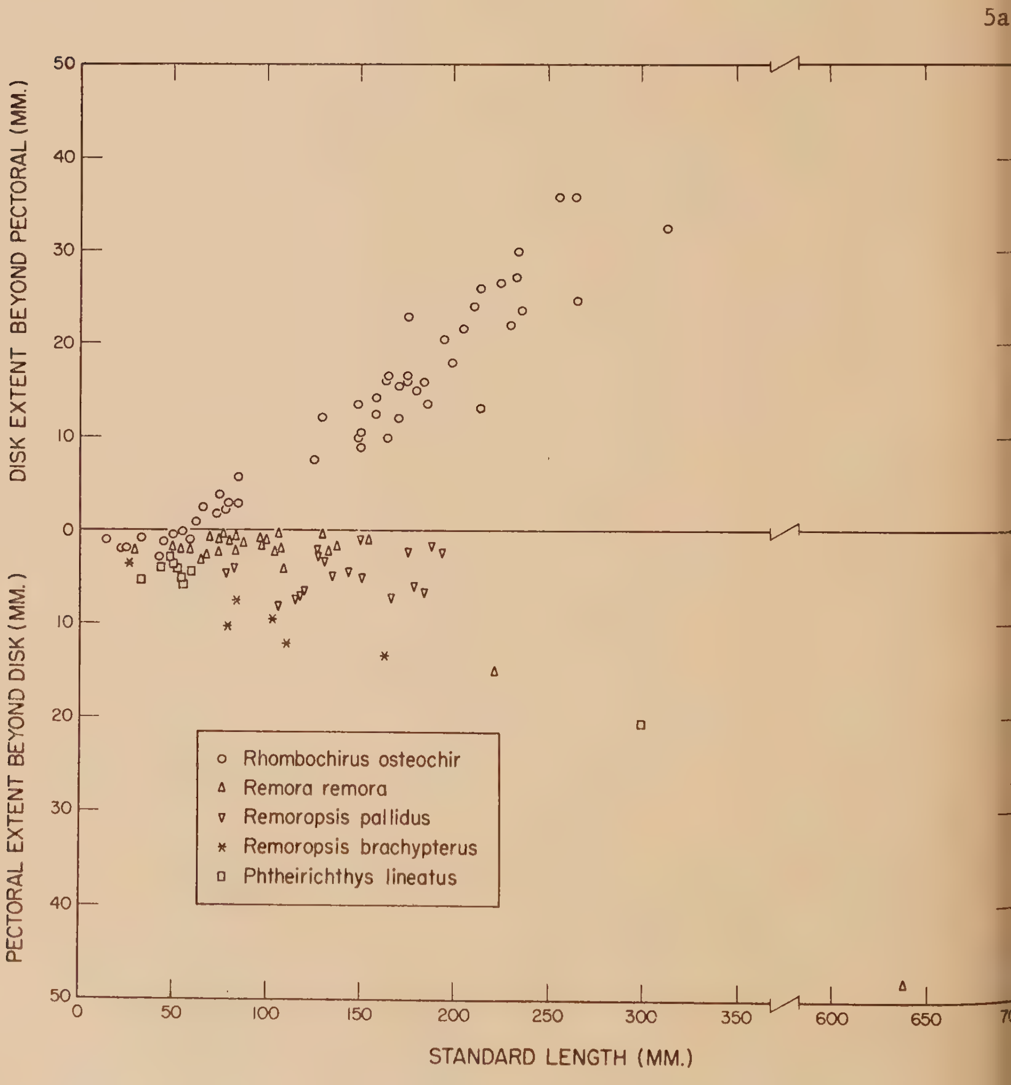

FIG. 1. Relative posterior extent of sucking disk and depressed pectoral fin for various echeneids.

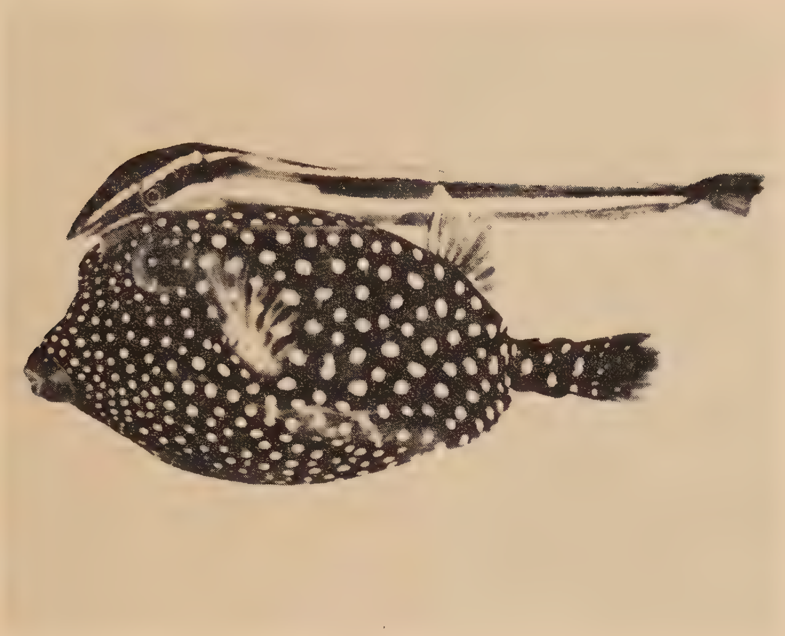

FIG. 2. *Echeneis naucrates* attached to *Ostracion lentiginosus*. Standard lengths estimated to be 57 and 49 mm respectively. (Photograph by Charles E. Cutress, U. S. National Museum.)

mmotile objects, *Remora* is found externally
sharks, and *Remoropsis pallidus* takes refuge
eath the opercula of marlins. Although it is
own that the early stages are planktonic, there
hitherto been no information on the size at
ich attachment first occurs, or whether there
trial hosts.

he material at hand indicates that the transi-
from the free-swimming to the attached
e occurs at about 40–80 mm standard length.
heirichthys then attaches to immotile ob-
s, as occasionally do some of the others.
ombochirus selects a variety of marlin-like
es for its attachment, while *Remora* attaches
harks. One of the *Echeneis* studied was at-
ed to a 49-mm trunkfish, *Ostracion lentigi-*
us (Fig. 2), collected on the reef at Waikiki,
u, Hawaii. Except for a few brief excursions
the host's belly, it remained inverted as
wn. Unfortunately, neither the echeneid nor
trunkfish was preserved, and their lengths
only estimates derived from the relative
ortions shown in the photograph. The second *Echeneis* could not be captured but was also about 50 mm in length. It joined me while swimming in 10-ft deep water at Beaufort, North Carolina. Its black and white pattern made it conspicuous, and it was sighted at a distance of 15 ft, swimming directly toward me. The fish made numerous attempts to attach to my black swim fins, touching them but not actually attaching because of my continuous movements. It eluded all attempts to capture it.

It would seem that attachment becomes obligatory somewhere in the 40 to 80-mm length range. Alternate hosts, such as *Acanthocybium, Tetrapturus,* and *Carcharhinus melanopterus,* may then be selected in the absence of the definitive host species. These small hosts may be regarded as trial vehicles because they bear only small echeneids. The size of the echeneids carried by them would be restricted by the relatively fewer ectoparasites available as food or, as in the case of the *Ostracion–Echeneis* association, by problems of list and drag resulting from a bulky adherent.

As a corollary, one would expect large echeneids to select large hosts or, in their absence, to revert to free swimming. The latter appears to be the case with *Echeneis naucrates*, 39-inch individuals of which are free-living around piers at Eniwetok, Marshall Islands (Strasburg, 1957: 60). The 640-mm *R. remora* listed in Table 2 confirms the first part of the hypothesis, for it was one of about three dozen individuals of similar size accompanying a 50 to 60-ft whale shark, *Rhincodon typus*, at Maro Reef (northwest of the main Hawaiian Islands). Attempts to lure this shark to the fishing vessel were unsuccessful because the chopped fish bait was intercepted by the darting remoras. Twelve remoras were caught by pole and line using tuna flesh as bait, but only a single specimen was preserved. Its stomach was empty, unfortunately, so that no light can be shed on its diet. It is doubtful that such a large fish could subsist mainly on its host's ectoparasites (cf Strasburg, 1959:246).

Some of the smaller specimens listed in Table 2 are the smallest reported representatives of their species. The 27.1-mm *brachypterus* is considerably shorter than Gudger's (1928) 77-mm fish, and my 14.3-mm *osteochir* is smaller than his 36-mm specimen. Gudger presents few descriptive data, however, and his specimens seem to differ from what are here called *brachypterus* and *osteochir*. On the basis of pectoral counts, Beebe's (1932) 15-mm "*Remora remora*" is *Rhombochirus osteochir*, while his 88-mm specimen is correctly identified as *R. remora*.

Beebe (ibid.) also misinterpreted certain morphological peculiarities of the lips and jaws of his small *osteochir*. These were stalked cup-like structures which he termed "suckers," and which he postulated were used for host attachment prior to the development of the cephalic disk. Actually the "suckers" on the mandible are the enlarged fleshy sockets which normally bear the fangs, while those on the upper lip are merely large pores. The fangs are easily extracted with forceps, imparting a sucker-like appearance to the supporting tissues. My 14.3-mm *osteochir* has seven outer and two inner fangs on each side of the mandible, making a total of 18 sockets. This is a reasonable approximation of the 20 "suckers" and four fangs which Beebe found in his 15-mm fish.

The young echeneid's need for its relative enormous fangs is presently inexplicable. The teeth are not deciduous but instead become i conspicuous through overgrowth of the gum and the appearance of other teeth between ther

Its intimate association with another speci could impose serious reproductive restrictio on an echeneid. Unless both sexes attached t the same host individual, spawning would b limited to times when the host species aggregated. Echeneids attached to hosts whic schooled or congregated to feed would hav many opportunities for mating, but those accompanying solitary hosts would have to spaw simultaneously with them.

The material at hand was examined for gona maturity and the presence of both sexes on th same host individual. Unfortunately, the spec mens were not always so segregated that th latter could be determined. Thus, although mature *Remora remora* and *Remoropsis pallidu* were found, it was not certain whether bot sexes had been attached to the same shark c marlin. The available *Remoropsis brachypteru* and *Phtheirichthys lineatus* were few and sexually immature.

In contrast to the above, the *Rhombochiru osteochir* data present a relatively clear pictur of the physical distribution of the sexes. Thi teen marlin and spearfish bore 2 *Rhombochiru* apiece. In 10 cases the 2 were a male and femal of the same size and degree of maturity (pairs were judged to be ripe, based on abdominal distension of the female). The 11th pair wa a small female and a fish half her size whos sex could not be determined. The remaining couples consisted of young fish of undetermine sex. A 14th host was accompanied by 3 *Rhombochirus*, a ripe male and female and a sma individual, one-fourth the length of the other whose sex could not be ascertained.

With 11 out of 14 pairs bisexual and in th same maturity stage, it would seem that *Rhombochirus* can reproduce quite independently o its host's aggregating habits. This does not mea that it always does so, for mature single *Rhombochirus* were also collected. In such case however, there is a possibility that these fis were remnants of pairs the other members o which had detached during the capture of th host.

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A POSSIBLE BREAKDOWN IN SYMBI- SIS BETWEEN FISHES.—Occasionally, a port on the Echeneidae will record speci- ens from the digestive tracts of large fishes ch as sharks, marlins, and tunas. Such currences have received little comment ecause they are infrequent and the sucker- sh are of negligible bulk in the predator's et. Their importance only becomes ap- arent when the situation is examined from ecological point of view. Such occur- nces then indicate a possible breakdown the symbiotic relationship in which many heneids have been found to pick parasites om their hosts (Szidat and Nani 1951, *ev. Inst. Invest. Mus. argent. Cienc. nat.* 6):413; Maul 1956, *Bol. Mus. Funchal* 9: ; Strasburg 1959, *Copeia* 3:247). This aper documents six additional instances of heneids having been eaten by large fish, d also gives an estimate of the frequency such a phenomenon.

The echeneids *Remoropsis brachypterus, hombochirus osteochir*, and *Phtheirichthys neatus* were found in the stomachs of yel- wfin tuna, striped marlin, and possibly so blue marlin, although this identifica- on is not certain and the fish may have een a striped marlin (Table 1). Identifi- tion of these partially digested suckerfish as in accordance with Maul (*op. cit.*:18–) where possible, although *Remoropsis llidus* was regarded as a synonym of *R. achypterus*. In three instances, the con- mer was also the host species (*T. audax* d *M. nigricans* commonly bear *R. bra- ypterus* and *R. osteochir*) so that the ckerfish prey could have been the hosts' eaners. In three other instances, the con- mer was not the host species (neither *R. achypterus* nor *P. lineatus* occurs on *T. albacares*, cf. Strasburg, *op. cit.* and *Pacific Sci.*, in press), and the fact that it ate suckerfish has litle ecological significance.

There are several possible ways by which these suckerfish could have been eaten. All of their consumers were captured by longline which had fished for several hours prior to being retrieved. During this time it would be possible for many echeneid-bearing hosts to be hooked, to die, and as often happens, to lose their suckerfish. Such detached echeneids could be easily picked off by a fast, hungry predator, and they might actually cause their own destruction by attempting to attach to passing foraging species. In my experience, yellowfin tuna do not normally bear suckerfish, and would probably regard any free-swimming individuals merely as food. On the other hand, one would expect the various marlins to exercise some restraint in eating a species with which they have a symbiotic relationship. If the cleaning relation between marlins and echeneids is historically in its early stages, it is possible that a hungry marlin might not always distinguish between its cleaner and its food. Other imperfect relationships, in which the cleaner is sometimes eaten, have been found among shrimp and moray eels (Limbaugh, Pederson, and Chase 1961, *Bull. Mar. Sci. Gulf Carib.* 11(2):250) and the kelp perch and other fishes (Limbaugh 1961, *Sci. Amer.* 205(2):45). Such relationships are intermediate between commensalism and true symbiosis. In the case of the shrimp, *Remoropsis*, and *Rhombochirus*, at least, the cleaner's lack of conspicuous coloration may lead to its occasional downfall.

Possibly the *R. brachypterus* eaten by *T. audax* had inhabited its host's buccopharyngeal region, but had become dislodged and

Table 1. Echeneids Eaten by Large Fish

Echeneid		Predator			
Species	Standard Length (mm)	Species	Weight (lb)	Region	Date
brachypterus	91	*Thunnus albacares*	110	02° S, 153° W	15 June 1962
"	123	" "	141	Off Hawaii	21 July 1960
"	170	*Tetrapturus audax*	81	Off Oahu	December 1962
osteochir	56	" " or *Makaira nigricans*	–	Off Kauai	15 June 1949
"	280	*Tetrapturus audax*	112	Off Oahu	September 1962
lineatus	46	*Thunnus albacares*	118	11° S, 135° W	28 August 1956

swallowed. Also, the various suckerfish listed above may have been dead prior to being eaten.

Two of the suckerfish listed in Table 1 were obtained from *T. audax* landed at the Honolulu Market. Messrs. Howard Yoshida and Frank Moriguchi, of the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, have undertaken a routine stomach sampling of the large market fish. They report that these two suckerfish were the only ones found in 749 stomachs having the following species distribution: *Makaira nigricans*, 96; *M. indica*, 5; *Tetrapturus audax*, 447; *T. angustirostris*, 16; *Istiophorus orientalis*, 21; *Thunnus albacares*, 97; *T. alalunga*, 24; *T. obesus*, 10; *Euthynnus pelamis*, 5; *Acanthocybium solandri*, 5; *Coryphaena hippurus*, 5; *Alepisaurus* sp., 15; and *Sphyraena* sp., 3. Considering only the 585 spearfishes and sailfish, which normally each bear at least two echeneids (Strasburg, *Pacific Sci.*, in press), the ratio of two suckerfish eaten out of more than 1,170 "available" is very low. Therefore, consumption of echeneids by these fish must be a rare event, probably fortuitous, and perhaps related to the fishing method used to capture the hosts.—Donald W. Strasburg, *U. S. Bureau of Commercial Fisheries, Biological Laboratory, Honolulu, Hawaii.*

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Postlarval Scombroid Fishes of the Genera *Acanthocybium, Nealotus,* and *Diplospinus* from the Central Pacific Ocean

DONALD W. STRASBURG[1]

EXCLUSIVE of the mackerels and tunas, whose commercial importance has caused them to be studied extensively, the early life history of scombroid fishes is poorly known. This is particularly true of the families Gempylidae and Trichiuridae, even though they are the bases for fisheries in Australia, South Africa, Madeira, and parts of Asia. There is also a paucity of life-history information about the non-schooling Scombridae. This paper describes young stages of the scombroid *Acanthocybium solandri* (Cuvier and Valenciennes), the gempylid *Nealotus tripes* Johnson, and the trichiurid *Diplospinus multistriatus* Maul, all three belonging to monotypic genera. The first has a slight commercial importance (Iversen and Yoshida, 1957:370), the others may be considered rare species of no commercial value.

The three families are taxonomically well known, the Scombridae having been reviewed by Fraser-Brunner (1950), the Gempylidae by Matsubara and Iwai (1952) and Grey (1953), and the Trichiuridae by Tucker (1956). All of these authors dealt essentially with adult fish. Postlarval *Acanthocybium* are hitherto unrecorded, the smallest specimen mentioned in the literature measuring 27 cm (Kishinouye, 1923: 387). Similarly, the smallest *Diplospinus* is 125 mm (Maul, 1948:45), although there is a possibility that a 69 mm *Lepidopus* may in reality be a *Diplospinus* (Tucker, 1956:81). Small *Nealotus* have been recorded by Lütken (1880:458), Günther (1887:35), Norman (1930:351), and Voss (1957:304). Lütken figured his specimens but regarded their identity as dubious. His larger specimen (about 13 mm standard length) has 20 spines in the first dorsal and is probably *Nealotus*. His smaller fish measures only about 8 mm in standard length and cannot be identified with certainty.

All material reported upon here was collected by "British Columbia" trawl during cruise 47 of the Bureau of Commercial Fisheries research vessel *"Hugh M. Smith."* This cruise took place in October–November 1958, in the central Pacific southeast of Hawaii. A description of the collection method is included in Matsumoto's report (in press) on the young tunas taken on this cruise. Figure 1 locates the trawling stations and capture sites of the species under consideration. Additional data may be found in Table 1 and in the species diagnoses.

Following capture, the fish were preserved in formalin and subsequently transferred to 65% ethyl alcohol. This particular concentration produced less wrinkling, hardening, and distortion than the customarily used 70% solution. Most specimens were stained with alizarin, but clearing the tissues, as with glycerin, was not done.

Thanks are due Messrs. G. Palmer, N. B. Marshall (British Museum), and G. E. Maul (Museu Municipal do Funchal) for supplementary information on *Diplospinus,* and Mrs. Nancy A. Voss (University of Miami Marine Laboratory) for data on *Nealotus.* The Inter-American Tropical Tuna Commission (La Jolla, California) loaned young *Scomberomorus.* I am also indebted to Tamotsu Nakata, Bureau of Commercial Fisheries Biological Laboratory, Honolulu, for preparing the figures.

Acanthocybium solandri (Cuvier and Valenciennes)

Station 60 1 specimen: 23.7 mm

The single *Acanthocybium* captured is rather easily recognizable in spite of the fact that its

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[1] Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii. Manuscript received November 13, 1962.

TABLE 1

STATION DATA, "HUGH M. SMITH" CRUISE 47

STATION NO.	DATE (1958)	ZONE TIME	LATITUDE	LONGITUDE	MAXIMUM HAUL DEPTH (in m)
2	Oct. 9	2005–2300	21° 24′ N	158° 23′ W	139
32	Oct. 27	1315–1523	00° 02′ S	149° 32′ W	85
49	Nov. 2	0843–1027	02° 09′ S	149° 47′ W	99
51	Nov. 2	2013–2158	00° 44′ S	149° 46′ W	85
53	Nov. 3	0838–1018	00° 37′ N	149° 58′ W	86
56	Nov. 4	1030–1210	01° 56′ N	150° 09′ W	98
58	Nov. 4	2013–2153	02° 56′ N	150° 03′ W	93
60	Nov. 5	0820–1002	04° 28′ N	150° 29′ W	96
66	Nov. 6	2005–2152	09° 08′ N	150° 03′ W	96
68	Nov. 7	0820–1007	10° 40′ N	149° 52′ W	93
70	Nov. 7	2015–2148	12° 13′ N	149° 56′ W	96

finlets have not yet differentiated. The fin formulae are D XXVII, 24 and A 22 as a consequence of persistent membranes between the fins and presumptive finlets. The anal formula is additionally misleading in that spines and rays cannot be distinguished. As is apparent from Figure 2, the spacing between the rays of the future finlets is greater than between the rays of the soft dorsal and anal fins. Further demarcating the finlets is the dusky pigment of their membranes. Following finlet formation this fish would presumably have had fin formulae of D XXVII, 14 + 10 and A 12 + 10.

Other characters of this specimen are 23 pectoral rays, I, 5 pelvic rays, 7 branchiostegal rays, and 17 principal caudal rays. All caudal rays, except the 5 mesial ones, have their bases covering the hypurals, tending to conceal the latter. The gill filaments are J-shaped but as yet show no tendency to fuse into the adult gill reticulum. Tooth size and spacing are irregular, in contrast to the homodont adult dentition, with about 28 teeth on each dentary and 25 on each premaxillary. The anterior teeth in both jaws are curved and fanglike. The anterior margin of the preopercle bears a short spine at the angle and another on the lower limb. The posterior margin has two short spines on the upper limb, a long spine at the angle, and five irregular spines on the lower limb. There are two tiny spines on the posterior tip of the pterotic, but these are too small to appear in the drawing. The body is dusted with tiny melanophores, giving a un form tan color, except on the dorsal part of th snout, which is dark brown.

An unusual feature of this specimen is conical cartilaginous projection surmounting th mandibular symphysis. This projection has bee noted in the adult, but not commented upo (Conrad, 1938:10). A similar structure ha phylogenetic significance in relating the Gem pylidae and Trichiuridae (Tucker, 1956:123 as well as taxonomic importance within th Gempylidae (Grey, 1953:138). Because its pres ence in *Acanthocybium* was thought to indicat hitherto unsuspected relationships between th Scombridae and the Gempylidae-Trichiuridae, search was made for the structure in othe scombroids. There is no indication of it in th young of any of the tunas (*Auxis, Euthynnu Germo, Katsuwonus, Neothunnus, Parathunnu* and *Thunnus*) according to W. M. Matsumot (personal communication), but a promine mandibular protuberance was found in juveni *Scomberomorus maculatus,* 11.5–19.2 mm standard length. *Scomberomorus* is regarded phylogenetically basal to *Acanthocybium* (Frase Brunner, 1950:135), and the presence of th jaw projection confirms a close relationshi That there is a tie between these genera and th Gempylidae-Trichiuridae is further indicate by their mutual low-crested crania, elonga compressed bodies, and reduced squamation. all scombroids examined, including a 565-m

Gempylus serpens, the jaw protuberance is flex-ble (and sometimes decurved in *Nesiarchus nasutus*), precluding its use as a spear, and instead suggesting a hydrodynamic function (cf Wisner, 1958: 68).

Nealotus tripes Johnson

Station 2	1 specimen:	176 mm
Station 32	10 specimens:	16.4–41.5 mm
Station 49	8 specimens:	19.6–25.8 mm
Station 51	59 specimens:	10.0–20.2 mm
Station 53	3 specimens:	10.0–22.0 mm
Station 56	4 specimens:	9.0–24.0 mm
Station 58	6 specimens:	21.2–25.0 mm
Station 60	2 specimens:	21.4–28.0 mm
Station 70	1 specimen:	37.0 mm

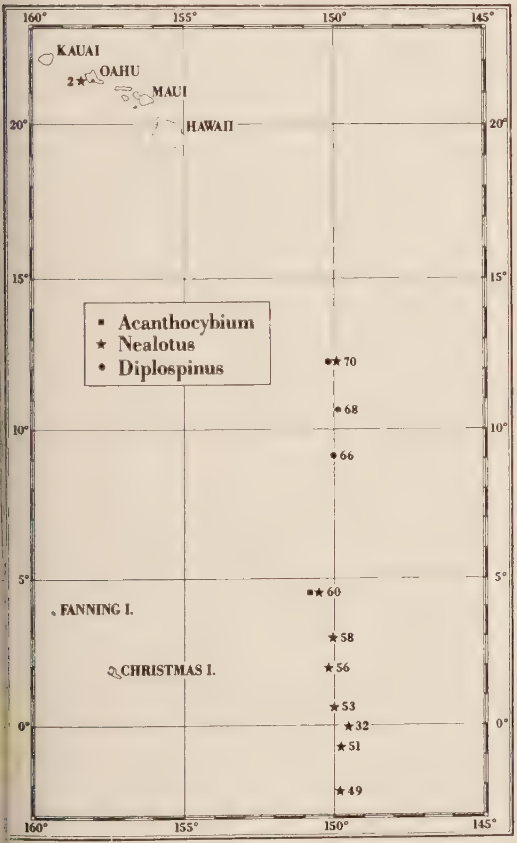

FIG. 1. Trawling stations on "Hugh M. Smith" cruise 47, showing places of capture of *Acanthocybium*, *Nealotus*, and *Diplospinus*.

When first examined, the smaller specimens listed above were thought to be *Nesiarchus nasutus* Johnson, to which they bear a strong superficial resemblance (cf Voss, 1954). Subsequent staining revealed their salient taxonomic feature, a reduction in the number of pelvic rays, showing that they belonged in a different branch of the Gempylidae, the *Rexea-Promethichthys-Nealotus* group. According to Grey (1953:139), these genera are characterized by a reduction of the pelvic fins to a pair of spines, or by the total absence of these fins. Only the largest of the above specimens, a fish 176 mm in length, has the pelvics reduced to mere spines and thus is referable to *Nealotus tripes*. The remainder range from 9.0–41.5 mm, and have pelvic formulae of I,2 or occasionally I,1 (Table 2). In this length range, as is shown in the following paragraphs, the pelvic rays gradually become overgrown by abdominal tissues, within which they are clearly visible after alizarin staining. At larger sizes the rays presumably are too deep to be seen without dissection or staining. Norman (1930:351) failed to find them in *N. tripes* specimens 53 and 88 mm long. Dissection of the pelvic region of my 176-mm fish revealed fragments of raylike material in the musculature ventral to the pelvic bones. These fragments were fused to the pelvis anteriorly, and appeared to serve as anchoring struts.

In young *Nealotus* individuals there are two prominent spines preceding the anal fin, whereas adults are generally regarded as having only one. My 176-mm specimen conforms to the adult concept externally, but when dissected its perianal region contained a small, flat spine, triangular in outline, embedded behind the first. Matsubara and Iwai (1952:207) also noted a second anal spine, but in their 199-mm fish it is shown as being externally visible.

With an ontogenetic loss of pelvic rays and anal spines, the genus *Nealotus* (and perhaps others) becomes more difficult to define. Characteristic counts are given in Table 2, along with data for *Nesiarchus nasutus*, a species of similar appearance.

Figure 3 depicts the smallest *Nealotus* examined, a fish 9.0 mm in standard length. At this size the vertical fin rays have not all differentiated, the dorsal being XX-I,18 and the anal

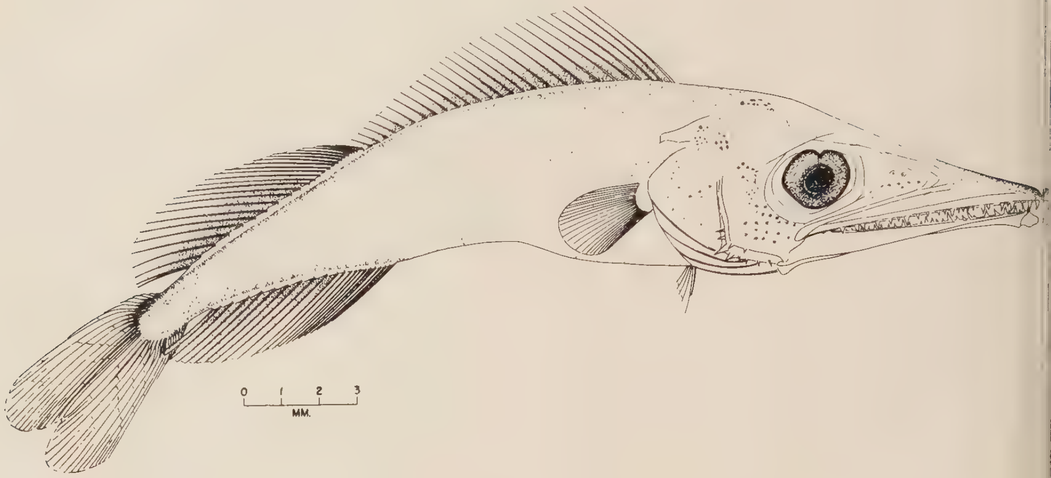

FIG. 2. *Acanthocybium solandri* 23.7 mm in standard length.

II-I,15, with both fins showing rudimentary raylike structures in the membranes posterior to the fins. The principal caudal rays number 9 + 8, the pectorals 13, and the pelvics I,2. Each pelvic spine is long, triradiate in cross-section, and spinigerous on all three edges. The inner pelvic ray is not only much shorter than the outer, but is also membranously bound to the belly anteriorly, whereas the outer ray is free. Like the pelvics, the dorsal spines are triradiate and spinigerous, with the degree of spinulation decreasing posteriorly. The first two dorsal spines bear spinules on all three edges while the rest bear them only laterally; in addition, the number of spinules per spine decreases toward the rear of the fin. The anal spines are like two spiny-edged, short-handled spoons, attached by the bowls with the convex side forward, and the second nesting into the first.

The preopercle bears two strong denticulate spines at its angle and two short smooth spines on its lower limb. The pterotic has two slender spines almost perpendicular to the body surface. A row of 10 denticulations above the eye completes the head armament.

The mandible is prognathous and its tip is surmounted by a small cartilaginous pad. The mandibular symphysis is edentulous, but there are two retrorse fangs on either side of it. About seven short upright teeth are borne on the dentary. There is a large fang on each side o the premaxillary symphysis and a larger one posterior and mesial to the first. About 13 other teeth, some little more than denticulations, occur on the premaxillary. The palatines lack teeth while the vomer bears a single prominent tooth at each posterior tip.

Pigmentation consists of a brown streak from the top of the head to the rear dorsal base, plus diffuse brown color around the dorso-anterio orbit and along the premaxillary. There is some inconsistency between specimens, probably re flecting differences in chromatophore contrac tion at death rather than the presence of mor than one species.

The 15.6-mm fish shown in Figure 4 differ from the 9-mm one principally in having achieved the adult fin complement (D XX- 19 + 2; A II-I, 16 + 2). The two dorsal and ana finlets are connected to each other and to th preceding fins, being detectable only by a varia tion in spacing. The pelvic spines are as befor but the rays are now adnate to the belly fo about half their length. The anal spines hav developed a keel on their previously smoot anterior surfaces.

The head armament consists of the two spin at the angle of the preopercle (these now havin lost their denticulations), two short spines o the lower limb of the preopercle, a single pe pendicular spine on the pterotic, and two po erior spinelike extensions of the strengthening ibs of the opercle. The supraorbital denticula-ions have been reduced to one or two.

Both the mandible and the upper jaw now ear small cartilaginous symphysial pads, and he dentition is much advanced. Besides the nterior pair of fangs, each dentary has 11 lightly retrorse teeth, and 12 similar teeth are found along the edge of each premaxillary. Anteriorly the premaxillary has 3 or 4 large urved fangs, the posterior ones longest, and ll larger than the fangs on the dentary. The vomer has a posterior tooth on each side, and there are about 4 slender teeth located on or near each palatine. Those which are merely near the palatines lack ossified bases. There are as yet no gill-rakers on the first arch.

Pigmentation is again inconsistent between specimens, except for a pronounced dark spot between the first two dorsal spines. Well-marked individuals are colored as is the 9-mm fish; others lack the dark pigmentation of the head and dorsal fin base.

At 31.0 mm (Fig. 5) many of the larval features have been replaced by juvenile characters. The dorsal finlets are still interconnected

TABLE 2

Counts Made on *Nealotus tripes* and *Nesiarchus nasutus**

PART	NO.	*Nealotus tripes* (No. specs.)	*Nesiarchus nasutus* (No. specs.)
First dorsal			
spines	19		21
	20	62	2
	21	1	
Second dorsal			
spines	1	63	23
rays	17	26	
	18	35	4
	19	2	8
	20		10
	21		1
Dorsal finlets	2	63	23
Anal			
spines	2–1	25	23
rays	15	2	
	16	14	4
	17	9	17
	18		2
Anal finlets	2	25	23
Pectoral			
rays	12		2
	13	24	21
	14	1	
Pelvic			
spines	1	64	21
rays	0	1	
	1	5	
	2	58	
	4		3
	5		18

* Standard length range: *Nealotus*, 10.0–176 mm; *Nesiarchus*, 11.7–105 mm. Finlets listed as such even if attached to fins persistent membranes.

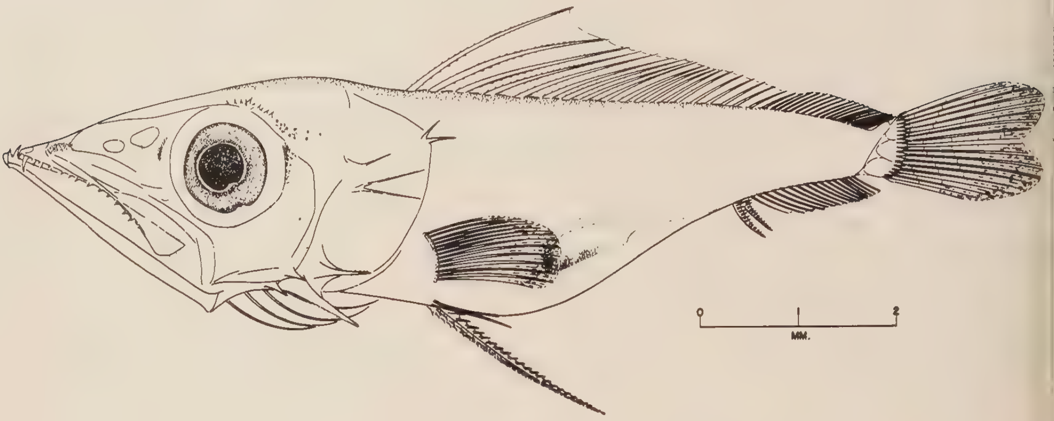

FIG. 3. *Nealotus tripes* 9.0 mm in standard length.

but are free from the last dorsal ray. The same is true of the anal finlets, except that there is a persistent basal membrane between the last anal ray and the first finlet. The dorsal spines have lost the spinules from their anterior edges, and the lateral spinules are less prominent on all fin spines, the space between the spinules having become filled with bony material. The pelvic rays are both buried in epidermal tissues, with the short mesial ray lying deeper than the long lateral one.

The upper spine at the preopercular angle is prominent, but the lower is broad and scarcely noticeable. The lower preopercular limb is smooth, and the opercular spines are reduced in size. The cartilaginous protuberance at the tip of each jaw is conical and well developed. The dentary has 2 anterior fangs and 13 variably smaller teeth; the premaxillary bears 3 anterior fangs and about 16 smaller teeth. The vomer has 2 teeth on each posterior tip, and there are about 6 teeth on or near each palatine. As before, some of the latter are attached to unossified material on the roof of the mouth. There are 3 + 1 + 8 gill-rakers on the first arch, the one at the angle being much larger than the others.

A new feature is the lateral line, a few scales of which are visible on the 31-mm fish. These lie in the skin and are better developed and more numerous anteriorly. In a 35-mm specimen (not shown) the lateral line is nearly completely developed. It is a tubelike structure containing 78 scales and extending from the head to the caudal peduncle. Scale spacing is occasionally irregular, suggesting incomplete development or loss through damage.

Pigmentation consists of rows of tiny, close-set, dark dots, giving an over-all tan color. This is intensified on top of the head, at the jaw tips, along the dorsal base, on the sides of the caudal peduncle, and around the anal spines. The fins lack pigment except for a distal dark spo between the first three dorsal spines.

A 41.5-mm fish (Fig. 6) is essentially juvenile. Persistent larval features include the slightly denticulate fin spines, the absence o scales except in the lateral line, and basal membranes between the finlets. The pelvic rays are embedded, the two preopercular and two opercular spines are reduced in size, and the symphysial jaw pads are less prominent (and now decurved in the case of the upper jaw). Th teeth have increased slightly in number, ther now being 3 anterior fangs and 19 latera teeth on the premaxillary, 2 fangs and 16 latera teeth on the dentary, 8 or 9 teeth on each palatin (all firmly ankylosed to the palatine and non free on the roof of the mouth), and 1 or elongate teeth posteriorly on each side of th vomer. There are 94 scales in the lateral lin but none elsewhere. There are 3 + 1 + slender gill-rakers on the first arch. Pigmentatio is as in the 31-mm fish, except that there ar now indications of distal dark spots betwee the first four dorsal spines.

It is unnecessary to figure my 176-mm fish, for it has essentially the same features as the 199-mm specimen shown by Matsubara and Iwai (1952:208). As noted earlier, it differs in having the second anal spine embedded. Other data from my specimen are as follows. The lower jaw has a rudimentary symphysial pad, 1 or 2 anterior fangs on each side, and a row of 17 lateral teeth set closely together like the teeth of a saw. On the premaxillary are 3 large anterior fangs and a row of 21 closely-spaced lateral teeth. The symphysial pad of the premaxillary is blunt, decurved, and scarcely noticeable. The roof of the mouth is overgrown by membranes which, when removed, reveal an edentulous vomer. There are 8 short, blunt denticles on each palatine. The gill-rakers consist of numerous spinules so variable in size, position, and spacing that they cannot be enumerated (cf Matsubara and Iwai, 1952:209). The specimen is partially skinned and the lateral line scales cannot be counted.

Diplospinus multistriatus Maul

Station 66	2 specimens: 103 and 166 mm
Station 68	10 specimens: 10.0–17.4 mm
Station 70	1 specimen: 156 mm

The genus *Diplospinus* is known from Madeira, the West Indies, and the Philippine–East Indian region (Tucker, 1956:79). The above specimens are the first from the central Pacific Ocean. Postlarvae are hitherto unknown, although they and earlier stages have been found for other trichiurids (Delsman, 1927; Padoa, 1956:508–513; Regan, 1916:144–145). The following descriptions and figures illustrate development in which a short, high-bodied postlarva becomes an increasingly attenuate juvenile.

As pointed out by Tucker (1956:81), there is a possibility that *Diplospinus multistriatus* Maul is a synonym of *Lepidopus gracilis* Brauer. The latter was described from a specimen 69 mm in length (Brauer, 1906:291), which differs from *multistriatus* chiefly in characters which change with growth. Although it was impossible to examine the type of *gracilis,* a brief study was made of a feature thought to distinguish it from *multistriatus,* the ratio of standard length to head length. This ratio is plotted against standard length in Figure 7. The data represent the present specimens, the type series of *multistriatus* as described by Maul (1948:45), a recently collected 65-mm *multistriatus* with a SL/HL ratio of 5.5 (Maul, in litt.), and the type of *gracilis.* The curve was derived from the regression of head length on standard length, $\hat{Y} = 3.397 + 0.1350X$, calculated from the above *multistriatus.*

From Figure 7 it would seem that *multistriatus* and *gracilis* are separate species. This is confirmed by the fiducial limits of the head length of *multistriatus* 69 mm in standard length (the length of Brauer's *gracilis*). At this size one can expect a head-length range of 12.3–13.1 mm, using $P_{.01}$ values of t and the formula

$$S\hat{Y} = \sqrt{\frac{1}{n} + \frac{x^2}{Sx^2}}$$

(Snedecor, 1946:120). The 14.25-mm head

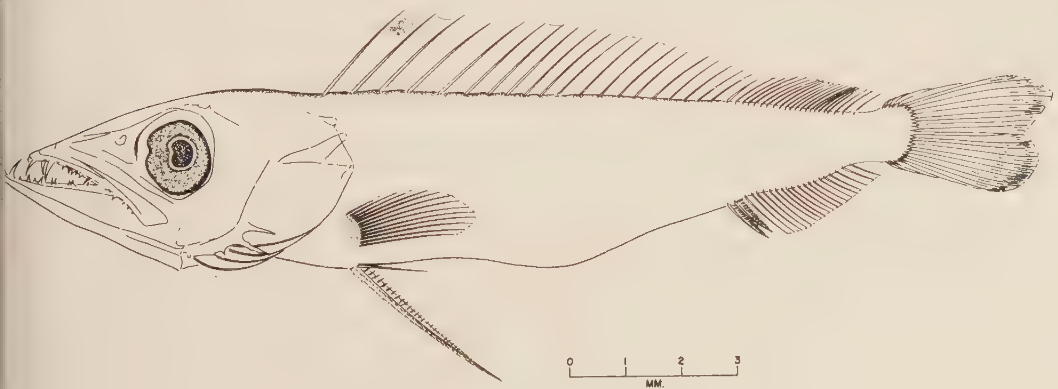

FIG. 4. *Nealotus tripes* 15.6 mm in standard length.

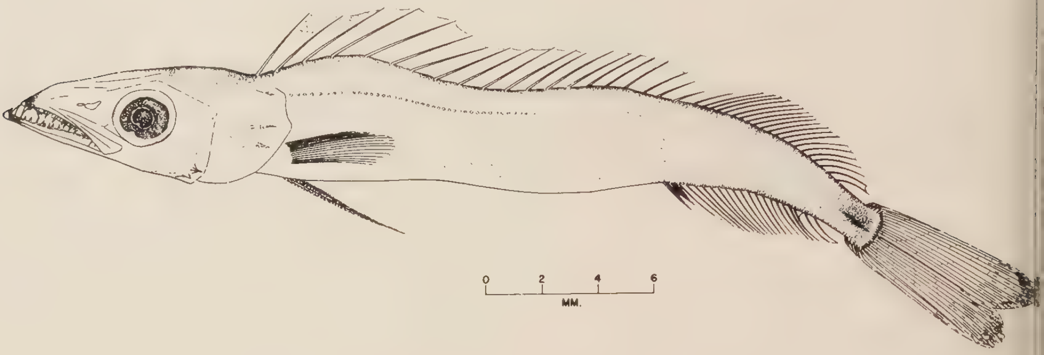

FIG. 5. *Nealotus tripes* 31.0 mm in standard length.

length of *gracilis* lies significantly distant from this range, and the two forms are therefore considered distinct species.

Because not all postlarvae in the 10.0–17.4 mm length range have acquired the adult fin ray complement, it is necessary to list meristic and length data conjointly in Table 3. The number of dorsal and anal fin rays increases irregularly with size. The pectoral, pelvic, and caudal fins and the branchiostegal rays show little or no meristic variation. Except for one specimen with 13 rays on one side and 12 on the other, the pectoral was constant at 12 rays. There were 7 branchiostegal rays and 9 + 8 principal caudal rays, the latter being difficult to count because of damage or nonattainment of definitive shape. In all 13 specimens the pelvic fins are represented by a pair of stout denticulated spines, in agreement with Maul's findings (1948:42) but not with Tucker's (1956: 79–81). The latter, working with a "completely skinned" paratype, observed "Ventral fin I–I
a narrow scale-like spine and an external spli
ray twice as long." Palmer and Marshall (in litt.
have re-examined this paratype but failed t
find the external split ray, observing only th
scale-like spine and the pelvic bones. I sugges
that Tucker's "ray" was in reality the splintlik
pelvis, perhaps loosened in its muscular bed b
the force which skinned the fish. In my speci
mens the attenuate pelvis bears a marked re
semblance to a soft ray and is, coincidentally
just twice as long as the pelvic spine.

The most distinctive feature of the 10.0-m
postlarval *Diplospinus* is its relatively grea
depth at mid-length. As shown in Figure 8, thi
is caused by a ventral distension of the belly b
the elongate pelvic bones, a condition reminis
cent of the Balistidae and Monacanthidae, excep
that in *Diplospinus* the pelvis extends poste
riorly. The great depth of *Diplospinus* is quit
different from the narrow belly of *Lepidopus* a

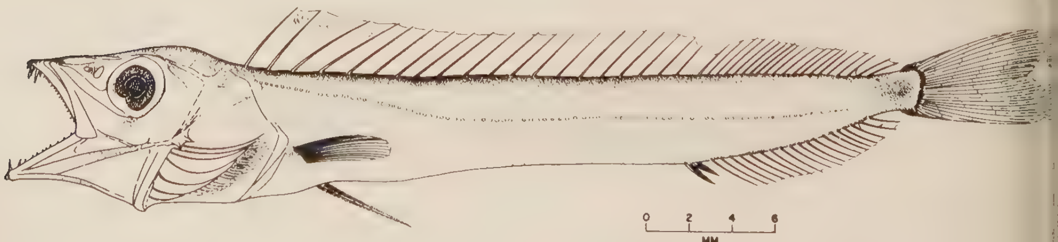

FIG. 6. *Nealotus tripes* 41.5 mm in standard length. The eyes are lacking in this specimen, but have bee
drawn as they appear in another of about the same size.

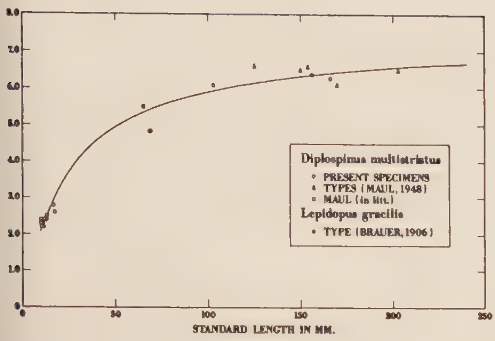

FIG. 7. Standard length/head-length ratio of *Diplo-*
inus multistriatus and *Lepidopus gracilis*.

is size (Regan, 1916: fig. 7). The abdominal
alls of *Diplospinus* are braced laterally by the
ry long, slender postcleithra.

Attached to each pelvic bone is a hyper-
ophied pelvic spine, V-shaped or nearly tri-
diate (through attenuation of the V's apex) in
oss-section, with about 20 spinules along each
its three edges. The two detached anal spines
d the anterior four or five dorsal spines are
nilar to the pelvics in shape and armament,
hile the others are smooth and less obviously
iradiate. The low number of soft dorsal rays
Table 3) is probably attributable to damage
ther than youth, for a 10.4-mm specimen has
more rays in this fin.

The head is armed with a long slightly ser-
ted spine at the preopercular angle, a shorter
ine just above it, and two other short spines
low, the last three spines being smooth. The
ree strengthening ribs of the upper opercle
oject from the opercular edge as slender
ines. Dorsal to these projections are two spines
right angles to the body surface: a stout ser-
ted spine on what is probably the pterotic,
d a slender smooth one on the post-temporal.
vo short spines occur above each eye.

A pair of stout anterolaterally directed tusks
s at each side of the symphysis of the prog-
thous mandible, these being ventral to the
v edge, horizontal in position, and unopposed
other teeth. Behind them are three or four
rorse denticles in the anterior half of each
ntary, with no teeth posteriorly. The pre-
xillary has an enlarged tooth at either side
the symphysis, one or two retrorse denticles
eral to this, and six or seven tiny denticles
scattered along the rest of its length. The vomer and palatines are ossified but edentulous. There is no trace of a cartilaginous jaw protuberance.

Pigment is restricted to a brown spot distally in the membrane between the first three dorsal spines.

At 13.2 mm (Fig. 9) the postlarva has become more elongate and less high-bodied. There is a variable increase in the number of dorsal and anal rays, and the spinigerous condition has spread posteriorly to include three-fourths of the dorsal spines. The caudal fin is beginning to fork. The preopercular spines are as before, while the post-temporal and pterotic spines are equal in size and both are smooth. The supraorbital spines are short and inconspicuous. A peculiarity of this specimen is its possession of only two opercular-strengthening ribs, each with a spinelike projection. The normal number of ribs, and spines, is three.

Just posterior to its nearly horizontal tusks each dentary bears an upright, unopposed tooth, and behind this is a row of eight emergent teeth extending to the rictus. The premaxillary has a pair of curved fangs on each side of the symphysis, followed by about six teeth of varying size extending to the rictus. The vomer has two prominent teeth on each posterior tip, while the palatines lack teeth. A cartilaginous pad has not yet appeared at either jaw tip. The nasal capsule is visible as a yellowish sub-epidermal sac which lacks external ducts.

TABLE 3

COUNTS MADE ON *Diplospinus multistriatus*

STANDARD LENGTH (mm)	DORSAL FIN	ANAL FIN
10.0	XXX, I, 16*	II–I, 19
10.4	XXX, I, 26	II–I, 20
11.1	XXXI, I, 25	II–I, 19
11.2	XXXII, I, 29	II–I, 22
12.0	XXX, I, 27	II–I, 23
12.1	XXXII, I, 27	II–I, 20
12.6	XXX, I, 30	II–I, 29
13.2	XXXI, I, 30	II–I, 23
16.5	XXXI, I, 33	II–I, 27
17.4	XXXI, I, 35	II–I, 28
103	XXX, I, 37	II–I, 31
156	XXXII, I, 35	II–I, 28
166	XXXII–I, 38	II–I, 30

* Damaged (?).

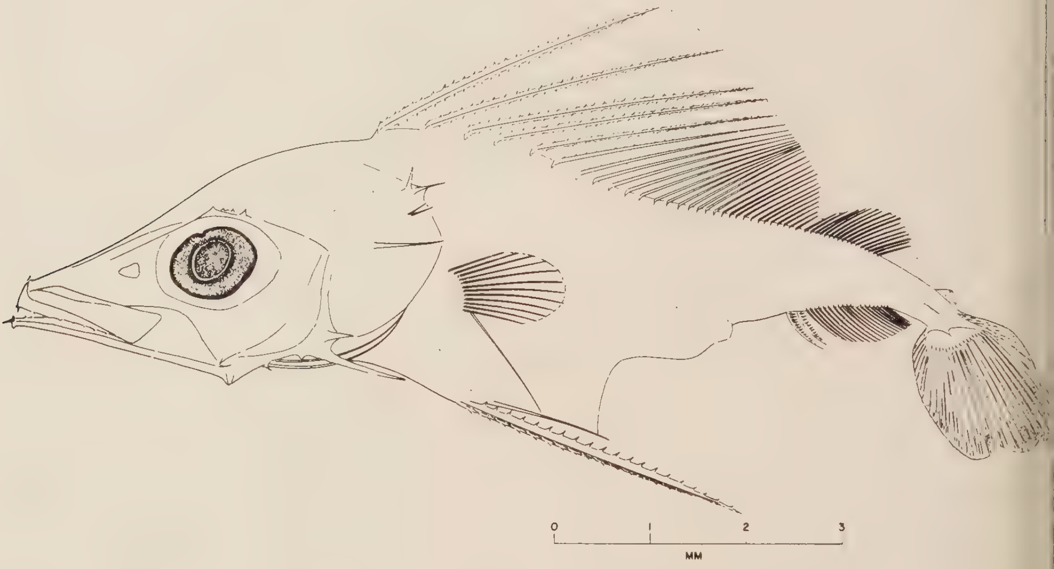

FIG. 8. *Diplospinus multistriatus* 10.0 mm in standard length.

Pigment consists of the distal brown spot in the spinous dorsal, large melanophores on top of the head and occiput, and diffuse brown color anterior to the eye, posteriorly on the maxillary, in front of the pelvic bases, and on the branchiostegal membranes.

Definite indications of the forthcoming ribbon shape are seen in the 17.4-mm postlarva (Fig. 10). There is little trace of the earlier abdominal distension and the head is relativel short. The adult fin ray complement has bee attained, although the fins are immature in tha their spines still bear spinules. The pelvics ar still excessively large and the caudal is wel forked.

On the head, the preopercular spines are a before except that those on the lower limb ar shorter and stouter. The opercular ribs an

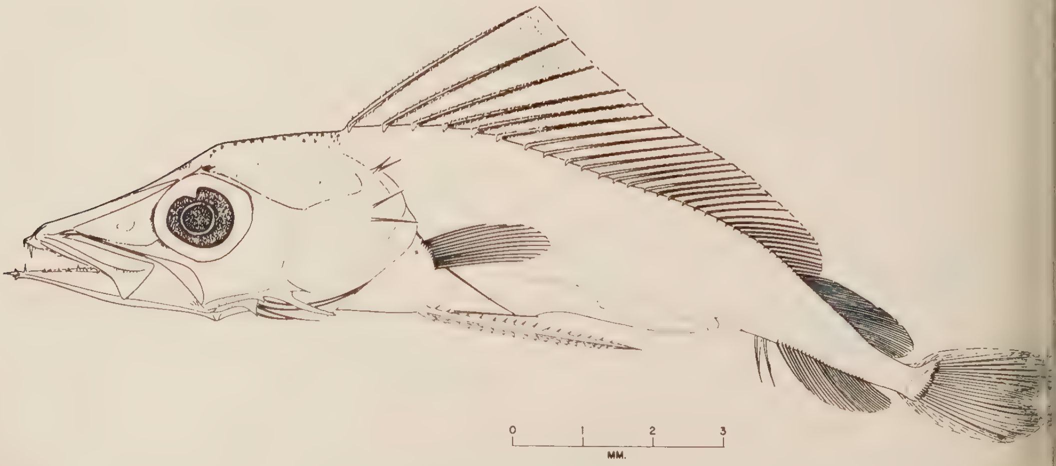

FIG. 9. *Diplospinus multistriatus* 13.2 mm in standard length.

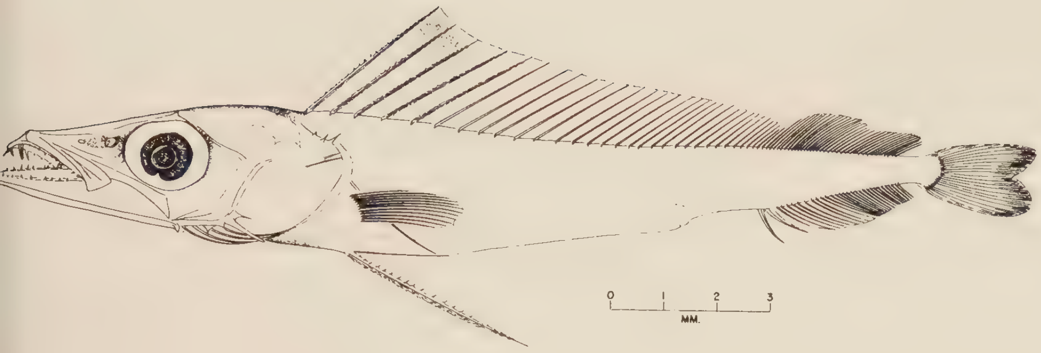

FIG. 10. *Diplospinus multistriatus* 17.4 mm in standard length.

ines and the post-temporal and pterotic spines
e likewise little changed. A single low spine,
tually little more than a crest, occurs above
ch eye. The upper of the two tusks on the
entary is much the larger, and the upright tooth
osterior to the tusks equals it in size. About
5 curved teeth, some occurring as pairs, occupy
e length of the dentary. Anteriorly the pre-
axillary has 3 or 4 greatly enlarged fangs, the
nterior 1 or 2 about half the size of the others.
ehind the fangs is a row of about 10 short
eth similar to those of the dentary. The vomer
ill has 2 teeth near each posterior tip, and
ese are attached on the inner surface of the
one rather than to its crown. Each palatine
ears 6–8 short denticles. There are 3 + 1 + 11
ng, slender gill-rakers on the first arch. The
sal capsule has 2 openings, an oval anterior
ostril and an irregular posterior one. The nos-
ils must form suddenly, for they are not pres-
it in a 16.5-mm specimen. Small patches of
rtilage surmount the tips of both jaws, where
ey appear to do nothing more than smooth
er irregularities in the bones.

Large melanophores occur on top of the head,
at give way to smaller ones which extend in a
rrow line from the occiput along the entire
se of the spinous dorsal. Dark pigment over-
s the nasal capsule and occurs as a ring around
e orbit. The maxillary, posterior dentary, and
e-pelvic and branchiostegal regions are also
sky, and there is a dark spot in the spinous
rsal fin membranes. (These membranes are
maged in the 17.4-mm fish and the spot is
awn as it appears in a 16.5-mm specimen.)

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Requirements of Gulf and South Atlantic Estuarine Research

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Requirements of Gulf and South Atlantic Estuarine Research[1]

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Abstract

In recent years biological research agencies became deeply concerned about estuarine alteration and the probability of its adverse effect on commercial fisheries. This concern stems from the recognition that most species occurring in Gulf catches spend a portion of their lives in estuaries. In 1962 the U.S. Bureau of Commercial Fisheries allocated funds for estuarine research in the Gulf of Mexico. Studies of the total estuarine complex are in progress. These include: (a) biological productivity and its relation to physical and chemical surroundings; and (b) the effects of natural and man-incurred alteration on estuarine biota and Gulf fisheries. As a part of the 1964 International Biological Year, a study of primary productivity in estuaries will be coordinated among a group of laboratories in the Gulf and South Atlantic Region.

HE TERM "ESTUARY" is subject to varying definitions and continues to be odified as estuarine studies intensify. At a recent research coordinating eeting of the Bureau of Commercial Fisheries, participants modified the finitions of estuaries by Ketchum (1953) and Pritchard (1952) and adopted e following concept:

> "Estuaries are those shallow waters with fluctuating salinities that differ from those of the adjacent sea. Usually, but not always, they are semi-enclosed bodies of water. Physical factors resulting from the mixing of fresh and salt waters and the resulting nutrient enrichment and high productivity of these waters constitute the unique features of estuaries."

e periphery of the Gulf of Mexico contains numerous indentations which ay be included in that description. Planimeter measurements show that ere are approximately 7,500 square miles of estuarine area extending from e southwest tip of Florida to Brownsville, Texas. This is exclusive of some ,500 square miles of adjacent, rich marshlands.

The real value of estuaries in their natural state is not generally recognized. dum (1961) stated that they are among the most naturally fertile areas in

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ontribution No. 5 of the Bureau of Commercial Fisheries Biological Station, St. Petersurg Beach, Fla.

the world and that they usually produce more dry organic matter per acre per year than fertile farm land or the sea. Odum (1959) compared primary productivity in a "cross section" of the biosphere ranging from the oceans, across continental shelf waters and through estuaries, marshes, and terrestrial communities (Fig. 1). He depicted productivity variation between various habitat types. Production is shown to be greater in estuaries and shallow water areas than in other sectors.

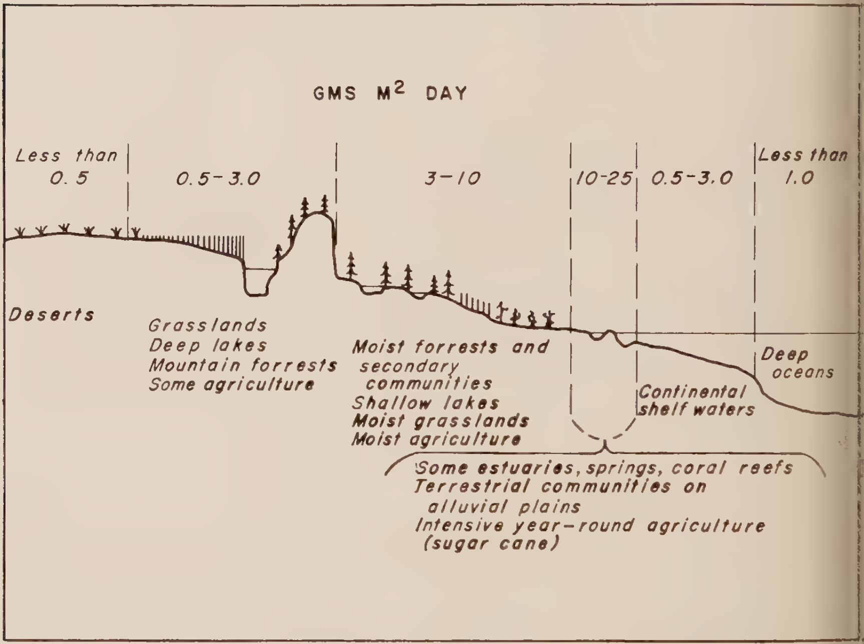

FIG. 1. World Distribution of Primary Production (Gms./m²/day). From Odum (1959) with permission of W. B. Saunders Company.

Hedgpeth (1957) stressed the importance of estuaries to the economy of neritic subtropical regions as nursery and feeding grounds. Skud and Wilson (1960) stated that the species which dominate Gulf of Mexico catches and account for 90% of the annual value are dependent upon estuaries as juveniles. Furthermore, Power (1962) showed that five estuarine dependent species, menhaden, shrimp, crabs, oysters, and mullet, comprised a catch of 1,131,000,000 pounds or 89.3% of the Gulf commercial catch in 1960. Our research in Tampa Bay has shown that at least 24 of the important species landed in Gulf fisheries occupy the estuary while immature (Table 1). Thus, it seems evident that Tampa Bay contributes to Gulf of Mexico commercial landings. The ex-vessel value of these landings in 1960 was $85,000,000 (Power, 1962).

In addition to the production of commercially harvestable species, estuaries provide excellent sport fishing and recreational areas. Sport fishermen land species which are commercially important as well as those not normally harvested by nets. One-sixth of all game fish landings in the United States are de in coastal waters. By the year 2000 this percentage will be increased one-third of total catches (Gresh, 1963).

TABLE 1

mmercially Important Species of the Gulf of Mexico Which Occur as Juveniles in the Tampa Bay Estuarine System

mmon Name	Genus and species
rge scale menhaden	*Brevoortia patronus*
llowfin shad	*Brevoortia smithi*
k shrimp	*Penaeus duorarum*
ite mullet	*Mugil curema*
ntail mullet	*Mugil trichodon*
iped mullet	*Mugil cephalus*
e crab	*Callinectes sapidus*
sters	*Crassostrea virginica*
ck grouper (gag)	*Mycteroperca microlepis*
d grouper	*Epinephelus morio*
anish mackerel	*Scomberomorus maculatus*
otted seatrout	*Cynoscion nebulosus*
d drum (redfish)	*Sciaenops ocellata*
efish	*Pomatomus saltatrix*
evalle jack	*Caranx hippos*
ck drum	*Pogonias cromis*
mpano	*Trachinotus carolinus*
epshead	*Archosargus probatocephalus*
tfin mojarra	*Eucinostomus argenteus*
er jenny	*Eucinostomus gula*
iped mojarra	*Diapterus plumieri*
t	*Leiostomus xanthurus*
d seatrout	*Cynoscion arenarius*
mit	*Trachinotus sp.*

The cultivation of estuaries in producing seafood has been practiced for turies by the nations of the Old World. For instance, the Japanese have nonstrated how shallow areas may be cultivated to supply large quantities edible protein (Cahn, 1950). We, too, should look toward better utilization our own estuaries and means of increasing seafood production.

The estuary has become a choice area for man's infiltration, particularly in theastern United States where lie some of the most fertile shallow water as of the nation. Increased population and industrial development usually e brought the following: (1) domestic sewage, soluble synthetic com- nds, and petroleum products, oftentimes dumped directly into the estuary, bulkheading, dredging, and filling for the creation of water-front home- s, canals, channels, and causeways (Fig. 2), (3) hurricane barriers to tect growing cities, (4) bottom scouring resulting from bulkheading, and sequent alteration of current direction and velocity, and (5) diking or nming to raise water tables, to create fresh-water fishing reservoirs, and to ment domestic water supply.

n view of the known importance of estuaries and the present rate of devel- nent within them, we are confronted with diverse research problems.

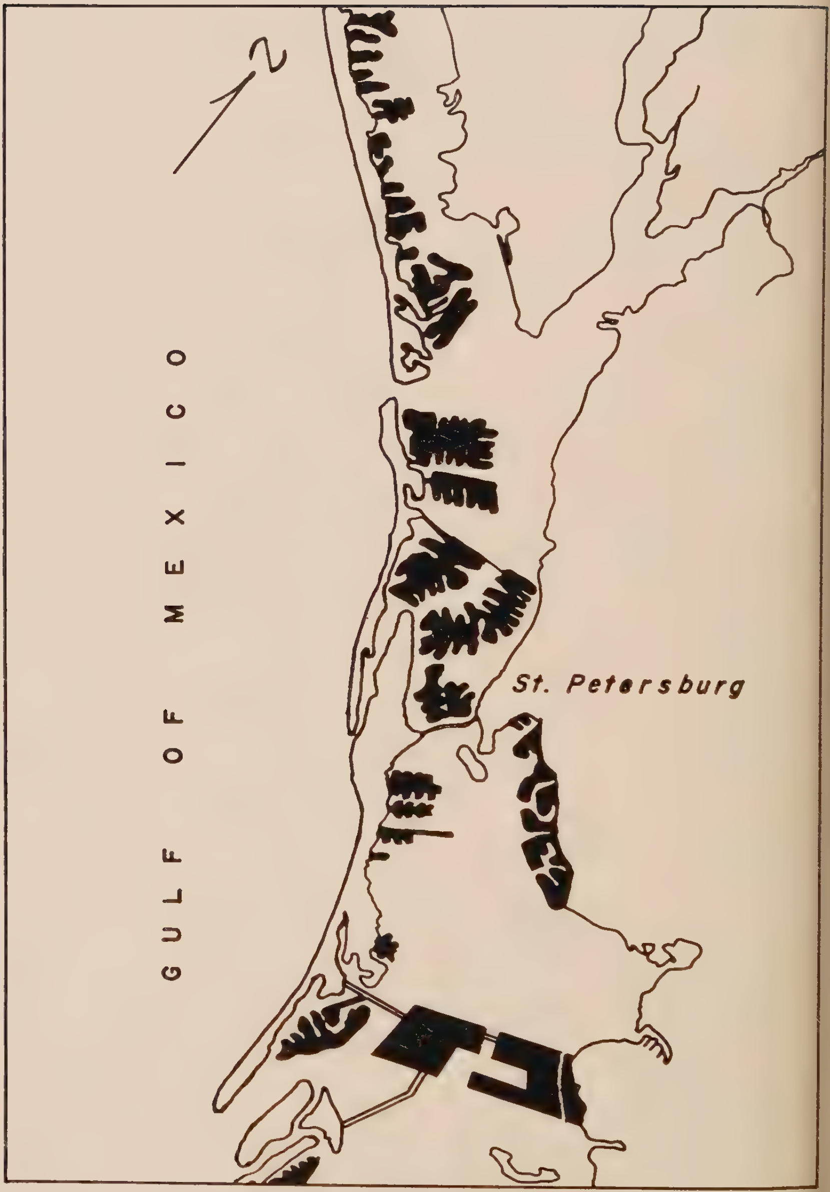

Fig. 2. Fill projects in Boca Ciega Bay, Florida, a part of the Tampa Ba
system. Darkened areas depict real estate sites created artificially.

ominent among these is the need for estimating the dollar value of estuarine ological resources and the extent to which major types of physical alteration ect biological production. We must also concentrate on the development of gulations and the modification of structures to insure protection of the reurces from damaging projects.

Regarding protective measures, Rounsefell (1963) urged caution in the formion of recommendations for managing estuaries. He emphasized that manageent formulae were dangerous when based on narrow aspects of the problem thout regard to the ecosystem complex.

The realization of those objectives requires a thorough understanding of rtilization mechanisms. Shelske and Odum (1961) listed five factors responle for a high rate of plant growth and subsequent productivity: (1) three imary production units (grass, mud algae, and phytoplankton; (2) tidal tion; (3) abundant supplies of nutrients; (4) conservation and rapid turner of nutrients; and (5) year-round production. Their list forms a standard r evaluating estuaries. Variation within the five factors and between invidual estuaries necessitates the investigation of each area under consideration.

Estuarine ecological research is underway at several federal, university, and ate laboratories in the Gulf and South Atlantic region. In 1963 representaes of Bureau of Commercial Fisheries laboratories in this region met to view estuarine research programs and to discuss programming and coordinan methods. Dr. Eugene P. Odum of the University of Georgia participated tively in discussions and planning. The following comments summarize briefly federal estuarine programs discussed at the conference. There is no intion of implying that these are the only estuarine programs in operation. ost of the universities and states located on the Gulf and South Atlantic asts are also active in this type of research, and in fact, communication d cooperative studies of mutual problems are advancing.

The U.S. Biological Station at St. Petersburg Beach, Florida, has undertaken following studies:

BENTHOS.

study of bottom ecology provides one of the better indicators of estuarine ndition. For that reason, results of benthic studies are useful in estimating effects of a changing environment. Series of sampling stations were ated on transects across Tampa Bay in a survey of benthic sediments and ociated biota. The stations cover the entire range of benthic types including ster bars, rock outcrops, and shallow, deep, mud, sand, shell, and grass bot. The association of benthic species with major substrate types is under estigation.

FAUNAL PRODUCTION.

is study is designed to account for species diversity, seasonal and areal upancy of animals in the estuary, and the dependency upon estuaries of mature forms which are essentially marine in their environmental requirents. At present, attention is being focused upon seasonal species distribu of fishes. A report on macro-invertebrates, their distribution and relation bottom type has been completed (Dragovich and Kelly, 1964).

HYDROLOGY-PLANKTON.

to- and zooplankton are basic elements in the food chain. The extent and position of their communities determines in large part the quality and productive capacity of an estuary. Analyses are being made of zooplankton volumes and associated hydrologic parameters (temperature, salinity, and total phosphate-phosphorus) obtained in the investigations over the past one and one-half years. Concurrently with present plankton collections, determinations of temperature, density, salinity, pH, oxygen, phosphate-phosphorus, transparency, and plankton pigments are also made.

4. WATER CHEMISTRY AND PRIMARY PRODUCTIVITY.

The object of this project is to study the relation of hydrologic conditions to biological production. The chemistry laboratory is presently engaged in analyses of salinity, total nitrogen, total phosphate, inorganic phosphate, oxygen, calcium, and pH. Chlorophyll A is being analyzed in conjunction with solar radiation measurements for conversion to primary productivity values. Ultra-violet absorption rates are determined for possible use as indices of dissolved organics. Age diversity of phytoplanktonic populations is measured by absorption ratios of an acetone extract.

In designing East Gulf Estuarine Investigations, those studies appeared to be the ones which have the most significant bearing on estuarine ecology and biological production. Studies of circulation, flushing, and transport characteristics are contemplated.

Other Bureau of Commercial Fisheries laboratories of the South Atlantic and Gulf region are engaged in similar studies, although emphasis varies with laboratory and location. At the Radiobiological Laboratory, Beaufort, North Carolina, the rates of production of benthic plants and phytoplankton are being compared in shallow estuaries. Experiments are being conducted to determine the factors controlling the productivity of estuaries and to develop methods for regulating their productivity. The cycling of elements is traced in experimental environments designed to simulate conditions in nature. Rates will be determined for the movement of radioactive tracers from water to sediments and communities of estuarine organisms. Existing levels of radioactivity in estuarine ecosystems are measured to be used as base lines for future comparisons in the event radioactivity becomes a significant environmental factor. Likewise, the potential effect of radiation as an environmental factor is being evaluated in relation to the growth, reproduction, and life span of estuarine organisms.

The Biological Laboratory (fisheries) at Beaufort, North Carolina has for several years been active in the study of marine and anadromous species and their dependence upon an estuarine environment during early development. The commercially important species under study include menhaden, shad, striped bass, and blue crabs.

Major problems at the Galveston, Texas Laboratory involve modification and destruction of estuarine and marsh habitat arising from pollution, exploitation of mineral resources, flood control and hurricane protection, development of water-borne commerce, and land reclamation projects. In an effort to insure that fishery resources receive adequate consideration in multiple-use development of estuaries the Galveston Laboratory is: (1) obtaining background ecological data to depict the importance, contribution, and value of Gulf estuaries to commercial fisheries and the relationship of biological populations to environmental characteristics; (2) assisting the Bureau of Sport Fisheries and Wildlife in determining the probable effects of water development projects on estuarine dependent fishery resources; (3) evaluating published d unpublished data describing and relating to Gulf coast estuaries; (4) operating with other agencies through the exchange of views, data, and sistance for mutual benefit: and (5) developing better methods for deter- ning specific effects of construction projects upon fishery resources, and ablishing criteria for project modifications that would best serve the interests fishery resources.

The Gulf Breeze, Florida Laboratory is engaged in intensive examination species diversity ratios by salinity regimes and by bottom type; also deter- nation of the normal seasonal fluctuations in abundance of some com- ercially important species. Data have been recorded for 15 continuous years seasonal fluctuations in appearance of sedentary organisms with parallel cords of hydrographic and meterological measurements.

The laboratory at Brunswick, Georgia, is situated in the center of the rich rsh area of the Georgia coast. This laboratory specializes in the taxonomy, velopment, and distribution of the fishes of the western North Atlantic. A rtion of the research takes place in estuaries of Georgia and northeast orida.

One of the major objectives of the coordination conference was to develop method for evaluating estuarine biological resources. It was recognized that ustry can and does attach a dollar value to its operations and projected ntribution to a community. Unfortunately, scientists and custodians of the tural resources have spent little time in converting information on bio-mass d productive potential to dollar estimates. The value of animals occurring the fourth trophic level or the worth of a relatively few pounds of fish rvested in a one-year period is usually cited when monetary evaluation is uired. In these instances unicellular plant production at the first trophic el, grazing herbivores at the second, or small carnivores at the third level not accounted for. Furthermore, there are usually no estimates made the value or potential utilization of energy existing between the first and rth trophic levels. These components must be studied, documented, and ognized before estuaries can be placed in competition with industry and d development activities.

The first unified effort between laboratories of the Bureau of Commercial heries and other interested state and institutional agencies will be to meas- total primary production. This consists of a light-dark bottle study statistical- designed to measure total production in grams of carbon per given time iod for the combined estuarine areas in the Gulf and South Atlantic region the United States. The study is designed to employ standard methods by cooperating laboratories. This effort will constitute an integral part of the 4 International Biological Year.

lthough the study of primary productivity represents the initial coordinated rt, other mutually designed studies are anticipated. These include investiga- of the role of detritus as food and structure in the habitat, assessment factors limiting biological production such as oxygen and food supply, the development of better ecosystem indices. Especially needed are means which engineering activities may be modified to conform with the biological uirements of estuarine organisms. Man-made structures such as hurricane iers, jetties, and artificial reefs might stabilize or even *increase* estuarine duction if engineered in accordance with recommendations of ecologists. instance, much loss of coastal oyster and clam beds has occurred as the result of siltation from hurricanes. Here, the protection afforded by some of man's devices would have been welcome. This is but one example of the need for methods of constructing and modifying artificial structures to benefit the resource rather than degrade it. This involves consultation with engineering and industrial agencies prior to construction.

The need for research specifically applicable to estuaries has been recognized for several years. Progress in initiating studies which attack a multiplicity of problems and areas has been gradual. Financial and technical support has now intensified so that promise of estuarine research on a large scale can be visualized. The combined effort in studying primary productivity on a regional basis is encouraging and is the first step to be taken in proving the potential value of southeastern estuarine systems. The coordinated study should produce facts useful to governing agencies in retarding and eventually ending that part of man's estuarine invasion which inhibits that value.

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tions. A 75-watt incandescent bulb, placed 8 inches above the water surface, provided continuous illumination. Since the experiments were conducted in a darkened room, the fish could be observed from an undetected position above the light source in the aquarium.

Brightening the aquarium light with a variable transformer was selected as the conditioned stimulus. The light intensity measured at 6 inches from the source was increased from 25 to 200 footcandles. This stimulus presented alone evoked no response from unconditioned fish. Food was selected as the unconditioned stimulus. As the light was brightened, dry food pellets were dropped into the water through a tube above the aquarium. In order to maintain strong hunger motivation, the fish were fed only enough food to evoke a feeding response. This response consisted of active surface feeding in the area where the food was introduced. Five minutes after each association the light was dimmed slowly to the original intensity. Associations were conducted at random intervals, and periodically the visual stimulus was presented without food to determine if the fish were becoming conditioned.

The conditioned response was similar to a normal feeding response. When the visual stimulus was presented to conditioned fish, their rate of swimming increased rapidly. This increase in activity was followed by group feeding behavior at the surface of the aquarium. Although the fish responded as a group, some individuals may have been cued by the movements of other fish. The response was not necessarily confined to the area where food was normally introduced.

In order to determine the rate of extinction of the conditioned response, 100 conditioned fish were transferred to an outside holding area. Here they were held in a 26-gallon fiber glass trough, which was flushed with dechlorinated city water at the rate of 45 gallons per hour. They were fed once a day with the same dry diet used in conditioning. Periodically they were moved back to the test aquarium, where after a delay of 4 days, the visual stimulus was presented without food. Each time the fish were moved from the aquarium, they were anesthetized with tricaine methanesulphonate (MS 222) to facilitate capture. I transferring them from the holding area t the aquarium, anesthetization was unnece sary.

RESULTS AND DISCUSSION

During a period of 16 days, 100 1-year-ol sockeye received 55 associations of the visu stimulus with food. In the same period th visual stimulus was presented without foo after every 11 associations. There was n discernible reaction to the visual stimul after the first 11 associations. After 22 ass ciations, there was a slight increase in activi and following the 33rd association, most the fish exhibited surface feeding behavi This response also occurred after the 44 association. No test for conditioning wa made after the 55th association, and the fis were transferred to the holding area.

No further associations were given, an tests for conditioning were made at the fo lowing daily intervals after the last associ tion: 20, 22, 34, 35, 45, 85, 254, 255, 25 282, 283, 284, 374, and 639. In each of the tests the visual stimulus was presented witho food. In all but three tests the fish responde with increased activity followed by surfa feeding behavior. On the 282nd and 374 days there was a definite increase in activit but surface feeding behavior did not occu On the 639th day the fish no longer exhibite the conditioned response.

To determine if there was any reinforc ment of the response within the holding are 20 juvenile sockeye which had not been co ditioned were held and fed in the same ma ner as the conditioned fish for a period 110 days. These fish were then moved to th test aquarium and were tested for conditio ing after a delay of 4 days. There was no i dication that any conditioning had occurre within the holding area.

During the study period the test fish we netted and moved 16 times and anesthetiz 8 times. They increased in average weig from 13 grams to 147 grams and underwe changes in coloration normally associat with smolt transformation (Hoar, 1958).

The results of these tests indicated that th conditioned response was relatively stable.

ditioned response to a biologically meanful stimulus in the natural environment ght be expected to have even greater staty.

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Serologically Differentiated Subpopulations of the Pacific Sardine, *Sardinops caerulea*

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Serologically Differentiated Subpopulations of the Pacific Sardine, *Sardinops caerulea*[1]

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ABSTRACT

Three genetically distinct subpopulations of the Pacific sardine have been differentiated by frequency of occurrence of a C-positive blood factor. Two of these subpopulations, a northern l a southern one, live off the coast of California and the outer coast of Baja California, Mexico. e third group inhabits the Gulf of California. The C-positive factor occurred in 13.6% of the thern subpopulation, 6.0% of the southern, and 16.8% of the Gulf subpopulation.

INTRODUCTION

IE EXISTENCE of more than one subpopulation of the Pacific sardine, *Sardinops rulea*, off the coast of California and Baja California was suspected for some ne before it was substantiated. Clark (1947) and McHugh (1950) recognized rphometric and meristic differences between the fish from the southern part the range and those from the north but did not know whether these characters re genetically or environmentally controlled. Other studies (Phillips, 1948; nda, 1953; Felin, 1954) have demonstrated differences in size-on-age curves ween ports and between seasons in the fishery. Marr (1957b, 1960) presented nprehensive reviews of the information pertinent to sardine subpopulations it has been collected over the years. Ahlstrom (1954, 1959) showed that at st four space-time spawning areas afford opportunities for genetic isolation l the possible existence of subpopulations. The definition of subpopulation it is used here is that given by Marr (1957a): "A subpopulation is a fraction a population that is itself genetically self-sustaining. It is the smallest natural f-perpetuating unit . . . although differences between subpopulations may be all, they are heritable."

In 1957, Lucian Sprague initiated a serological study on Pacific sardines. his studies of the erythrocyte antigens, he was able to demonstrate two parently independent blood group systems which he called the B and C tems. The latter proved to be the more straightforward and trouble-free. the basis of the relative proportions of C-positive individuals he was able to tinguish two subpopulations of sardines off the coast of California and Baja lifornia, Mexico: a northern one with about 14% C-positive and a southern h about 5%. In a recent paper, Sprague and Vrooman (1962) described in ne detail the reagents, methods, blood group systems, and results of these dies through April 1960.

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nted in Canada.

This report adds data collected subsequent to the first report, and also add a third subpopulation to the two previously known. It is primarily an interpretation of the results with respect to recognition of the subpopulations usin the C-blood-group system, and delimiting their distributions; it is not concerne with the methods of determining blood group systems.

RESULTS AND DISCUSSION

The results of serological tests on 2844 sardines from various areas betwee Santa Cruz Island, California, and Cresciente Island, Baja California, mad between May 1960 and April 1962 are shown in Table I. The usual samplin procedure was to draw fresh blood from 100 individual sardines from a singl school. If the blood from an individual fish hemolysed or clotted before o during the test, the specimen was not included in the count. Some sample contain considerably more than 100 fish; in these instances, sardines from a singl school were held in a bait tank or a floating bait receiver, repeatedly sampled and reported as a single large sample. In a few cases, fewer than 100 fish wer available.

TABLE I. Frequency of the C+ antigens in the northern and southern sardine subpopulations

Area	Date	No. fish	No. C+	Percentag C+
		Northern		
San Diego	May 1960	100	15	15.0
"	July 1960	56	7	12.5
Santa Cruz Is.	Oct. 1960	88	10	11.3
San Diego	Nov. 1960	247	34	13.8
"	Jan. 1961	140	18	12.9
Catalina Island	April 1961	98	18	18.4
Del Mar	April 1961	99	14	14.1
Catalina Island	April 1961	99	14	14.1
San Diego	May 1961	80	13	16.2
"	June 1961	99	12	12.1
"	July 1961	100	11	11.0
"	July 1961	98	12	12.2
"	Aug. 1961	86	11	12.8
"	Nov. 1961	98	13	13.3
"	April 1962	98	13	13.3
		1586		$\bar{x}$ = 13.5
		Southern		
San Diego	July 1960	94	5	5.3
Magdalena Bay	Aug. 1960	100	7	7.0
San Diego	Aug. 1960	100	8	8.0
San Quintin	Aug. 1960	100	5	5.0
Sebastian Vizcaino Bay	Sept. 1960	100	5	5.0
Blanca Bay	Sept. 1960	74	6	8.1
San Pedro	Oct. 1960	100	6	6.0
San Diego	Oct. 1960	292	21	7.2
Magdalena Bay	Aug. 1961	99	7	7.1
Cresciente Island	March 1962	199	13	6.5
		1258		$\bar{x}$ = 6.5

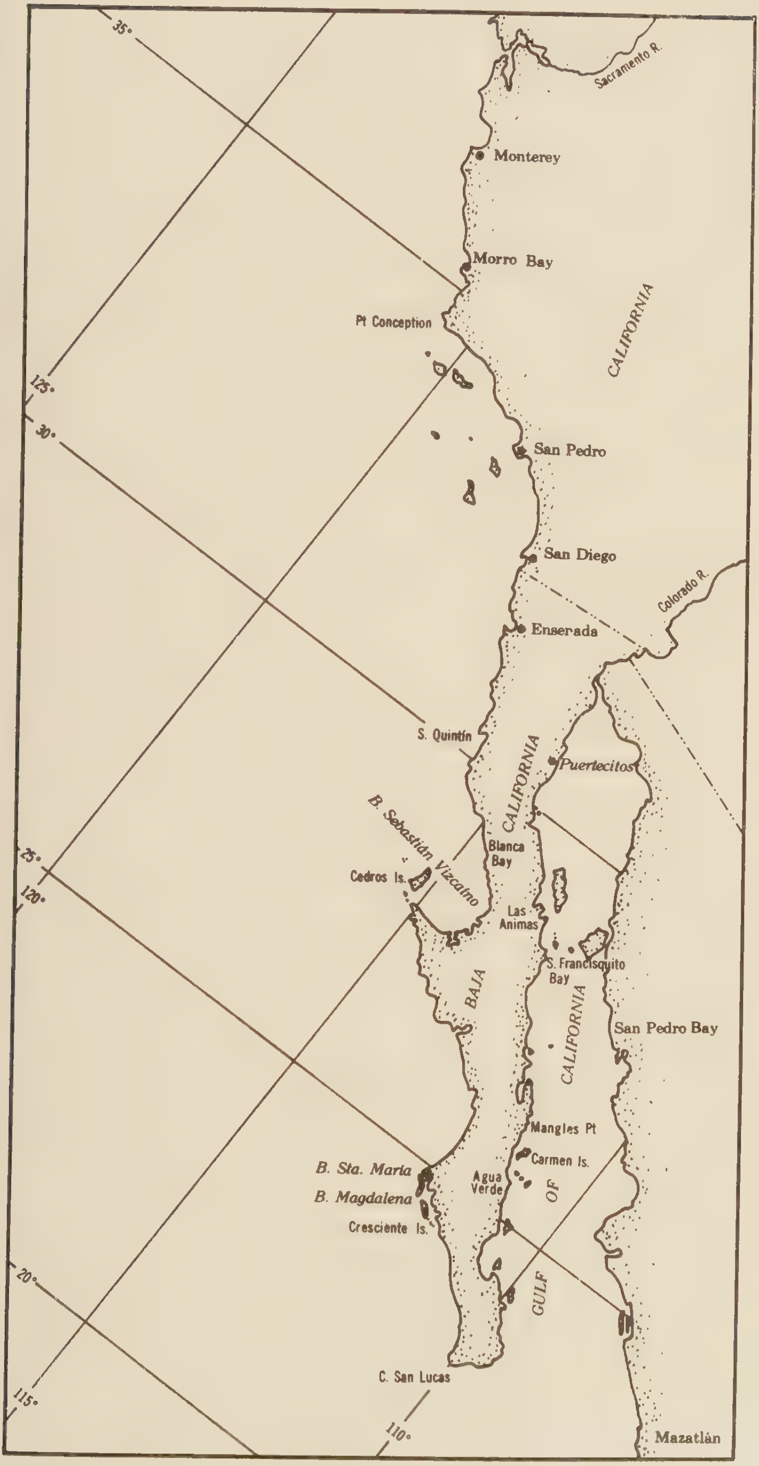

FIG. 1. Coast of southern California and northern Mexico.

Each sample listed in Table I was assigned to the northern or southern subpopulation on the basis of a high or low proportion of C-positive individuals. The 15 samples classified northern had an average of 13.5% C-positive fish (range 11.0–18.4%). All the northern subpopulation samples were obtained off southern California with the majority from the San Diego area.

The 10 samples classified as the southern subpopulation had an average of 6.5% C-positive sardines (range 5.0–8.1%). Six of these samples were obtained off Baja California, Mexico, 4 from southern California. The overlap in geographical range of the two subpopulations is discussed later.

These data indicate C-positive sardines occur about half as frequently in the southern subpopulation as in the northern. The mean of 13.5% C-positive sardines reported here for the northern subpopulation is very close to the 13.8% reported by Sprague and Vrooman (1962). The mean of 6.5% C-positive sardines for the samples classified as the southern subpopulation is somewhat higher than the 5.3% given in the earlier paper. The most reliable figures available for the mean frequency of C-positive sardines in each subpopulation is obtained by combining the samples reported in table 5 of Sprague and Vrooman (1962) with those from Table I of this paper. The mean for all 23 samples from the northern subpopulation is 13.6% (range 10.9–19.5%) with a standard deviation (S.D.) of 2.2%. The mean for the 17 samples from the southern subpopulation is 6.0% (range 3.0–8.1%), S.D. = 1.2%. The mean frequency of C-positive sardines in the northern subpopulation is significantly different from that of the southern ($t = 12.6$ with 38 degrees of freedom, $P < .001$).

Evidence of a third subpopulation was found in August 1961 when a sample of sardines was captured off Mangles Point in the Gulf of California (Fig. 1) which contained 16.8% C-positive sardines. This high proportion of C-positive more nearly resembled the geographically distant northern subpopulation than it did the adjacent southern subpopulation. Subsequently 7 more samples were obtained from other parts of the Gulf. The data from serological tests on 738 of these fish are presented in Table II.

TABLE II. Frequency of the C+ antigens in the Gulf subpopulation of sardines.

Area	Date	No. fish	No. C+	Percentage C+
Mangles Point	Aug. 1961	95	16	16.8
San Pedro Bay	March 1962	95	18	19.0
Puertecitos	March 1962	99	21	21.2
Los Animas Bay	March 1962	97	16	16.5
San Francisquito Bay	March 1962	53	10	18.9
Carmen Island	March 1962	100	16	16.0
Carmen Island	March 1962	98	12	12.2
Agua Verde Bay	March 1962	101	14	13.9
		738		$\bar{x}$ = 16.8

The mean frequency of C-positive fish is 16.8% (range 12.2–21.2%), S.D. .9%. The difference between means of the Gulf and the southern sub- ılation is highly significant (t = 13.3 with 23 degrees of freedom, P<.001); difference between the Gulf and the northern subpopulation means is signif- t at about the 1% level (t = 3.2 with 29 degrees of freedom, P = .006).

The data on the frequency of C-positive sardines in the three subpopulations graphically presented in Fig. 2. Each dot represents the frequency of C-posi- sardines in the individual samples listed in Tables I and II and in table 5 prague and Vrooman (1962). The triangles point to the calculated mean ach subpopulation; the bars over the top represent two standard deviations the mean on each side of the mean.

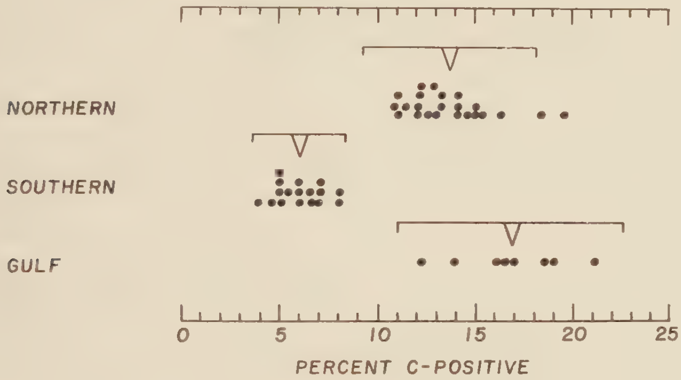

Fig. 2. Frequency of C-positive blood type in the three subpopulations, expressed as per cent.

These data confirm the conclusion of Sprague and Vrooman (1962) that the hern and southern groups are genetically distinct subpopulations of the fic sardine, and also indicate that the sardines inhabiting the Gulf of Cali- ia represent a third distinct subpopulation.

For the purpose of discussion it is necessary to define the terms interbreeding intermixing in the context of this paper. Interbreeding between two opulations is the exchange of gametes between individuals from both groups. rmixing is the mingling of individuals from both groups at times other than ning when there can be no exchange of gametes. Intermixing may take ral forms: (1) a school of fish from each of two subpopulations may combine one large intermixed school, (2) the two schools may remain separate but r in such close proximity in a water mass that they may be caught in a e set, (3) the two schools may occur some distance apart but could be mixed in the catch of one boat making two sets, or (4) the two schools be quite widely separated in the sea and caught by two boats which unloaded e same cannery. Owing to the method of collection, only intermixing of s (1) and (2) are possible in the samples of sardines taken for serological . All four forms may occur in sardine samples from the commercial catch, h furnished the data from which Fig. 3 and 4 were drawn.

It is assumed that the erythrocyte antigens of sardines are genetically controlled as in other species. Random interbreeding of the whole Pacific sardin population would break down the observed differences in the frequency of th C-positive phenotypes among the three known subpopulations in one year Partial interbreeding between the subpopulations would also result in a breakdown of these differences but would take longer. Little or no interbreeding i indicated by the significant difference in the frequency of the C-positiv phenotype between the northern and the southern subpopulations and the fac that these observed frequencies have remained virtually the same for thre consecutive years.

Intermixing may take place to some extent during part of the year, but a long as the spawning individuals segregate again into their own groups, genetically distinct subpopulations would persist. If intermixing between the norther and southern subpopulations occurred to a significant degree, it would be expecte to show up as a cline in the frequency of C-positive individuals in the sample of fish from the adjacent edges of the two subpopulations. The lower (southern edge of the northern subpopulation would have the best chance of intermixin with the southern group, the central portion of the northern group would hav less chance of intermixing, and the upper (northern) portion of this group woul have the least chance. Possible intermixing was tested by dividing the serologica samples listed in Table I together with samples listed in Sprague and Vrooma (1962) into upper, central, and lower portions of the respective subpopulation' range and calculating the frequency of C-positive individuals for each group The results are presented in Table III.

TABLE III. Distribution of C-positive sardines within the northern and southern subpopulations.

Northern subpopulation	
	%
Upper portion	14.10
Central portion	13.38
Lower portion	13.60
Southern subpopulation	
Upper portion	5.88
Central portion	5.99
Lower portion	6.25

There are no significant differences in the frequencies observed from th three geographical portions of the two subpopulations and no indications of cline of blood-type frequencies, hence no evidence of significant intermixin between the northern and southern subpopulations.

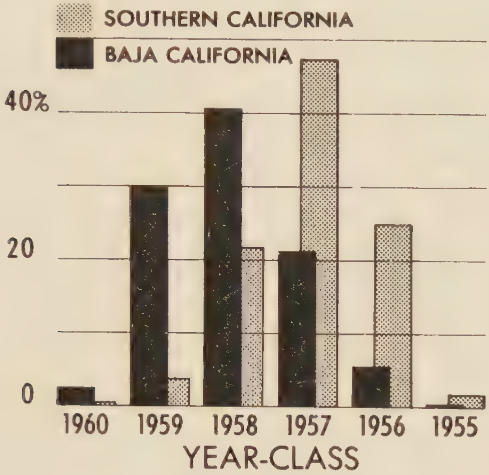

FIG. 3. Year-class composition of the Baja California and southern California commercial catch.

The sardines off California and Baja California have shown considerable seasonal movements up and down the coast. That there is generally a northward movement in the spring and summer with a return toward the south in the fall and winter has been demonstrated by tagging, by changes in availability, by the age-length compositions of the catch, and more recently by serology. The geographic ranges of the northern and southern subpopulations overlap considerably; southern sardines have been taken as far north as San Pedro and northern fish have been caught as far south as San Quintin Bay, 250 miles south of San Pedro. The extensive overlap in geographic range does not necessarily mean the two subpopulations overlap each other; instead, it appears that both groups shift north or south at about the same time of year and retain their positions relative to each other.

In the summers of 1959 and 1960, southern sardines were present in the San Diego area and were even taken as far north as San Pedro in early October of 1960. In both of these years there appeared to be a southward movement of the bulk of the sardine population off the coast of California beginning about mid October. This movement could be observed by the progression from north to south of the commercial fishing fleet as they followed the sardines. It was also indicated in the samples of sardines tested serologically by the disappearance of southern fish from the San Diego bait fishery and the reappearance of northern sardines. In the fall and winter of 1959 the northern sardines apparently continued moving farther south than usual. Serological tests from samples obtained on a research cruise during late February and early March 1960 disclosed northern sardines off Ensenada and in San Quintin Bay; southern sardines were caught in Blanca Bay, 370 miles south of San Pedro.

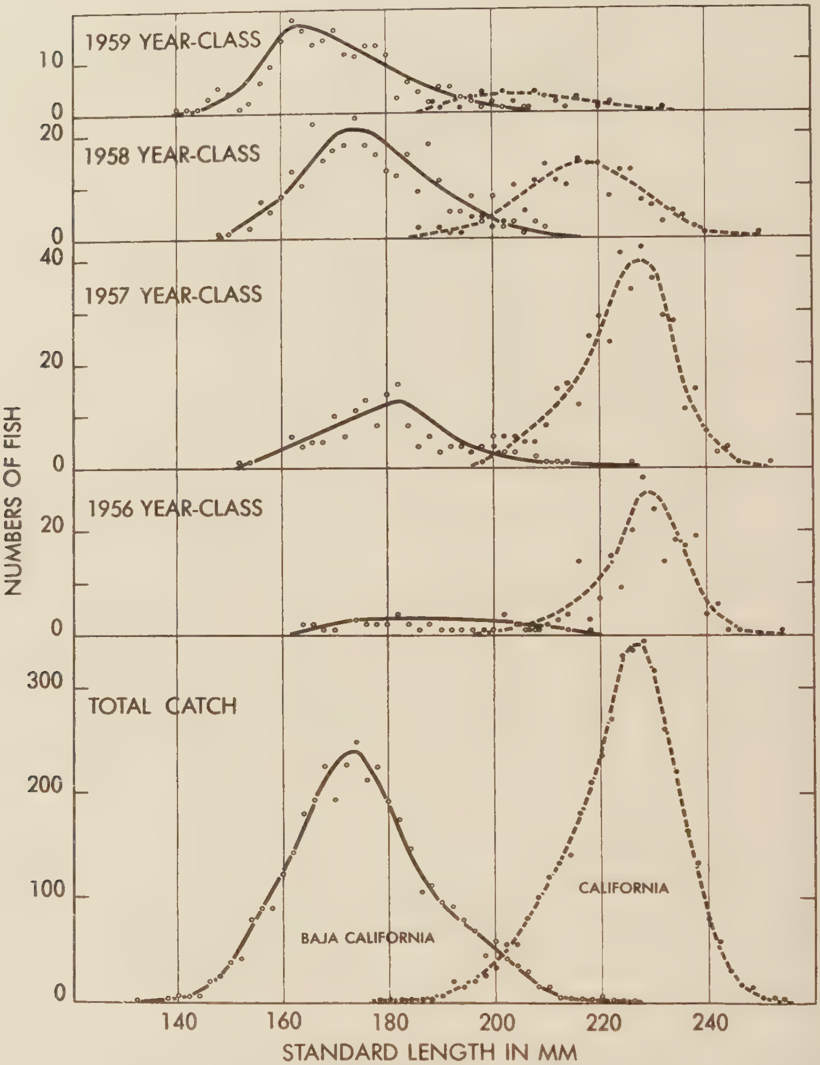

FIG. 4. Length composition of the Baja California and southern California commercial catch.

The pattern of movement changed somewhat in the 1961–62 season. Th southern subpopulation had moved far to the south during the fall and winte of 1960. On a research cruise in February 1961 no sardines could be found fron the Mexican border to Cedros Island. The lack of sardines in this area was als indicated by the Mexican commercial fishing fleet which was operating almos entirely south of Sebastian Vizcaino Bay. Later in the spring and summer th sardines moved north somewhat so that some commercial catches were made i the northern part of Sebastian Vizcaino Bay and the San Quintin Bay area, whic was still unusually far south. No southern sardines were found in serologicall tested samples from San Diego during the summer and fall. This would indicate that, unlike the two previous seasons, the southern subpopulation did not move far enough northward during the year to enter United States waters and could not have contributed to the United States commercial catch for the 1961–62 season. This was a fortunate circumstance from the point of subpopulation studies because for the first time we were able to relate the data collected from the commercial catch to a specific subpopulation. All the landings from southern California are considered to be from the northern subpopulation: most of the landings from Baja California are probably from the southern subpopulation. A very few catches of sardines were made between Ensenada and the United States border. These fish may have been from the northern group, but they made up such a small fraction of the total landings at Ensenada that they would not significantly influence the data. The 1961–62 southern California commercial sardine fishing season opened in Septenber 1961 and closed in February 1962. The Baja California catch statistics for the same interval are used in the following comparisons.

The year-class composition (Fig. 3) of the southern California catch was quite different from that of Baja California; the former was composed of older fish with the 1957 year-class dominant; the latter was composed of younger fish with the 1958 year-class dominant. The length compositions of the individual year-classes and of the total catches (Fig. 4) were also very different. The size frequency of the total catch of Baja California had a mode at about 175 mm standard length compared to a mode at around 228 mm for southern California. The larger size of the fish in the southern California catch was not primarily due to the older average age. Fish of the 1956 through 1959 year-classes were markedly larger in the southern California catch (northern subpopulation) than fish of the same ages in the Baja California catch (southern subpopulation) (Fig. 4). These differences in both year-class compositions and sizes at given ages of the two groups support the serological evidence of distinct northern and southern subpopulations.

Reproductive isolation between the Gulf and the southern subpopulation is provided over most of their range by the physical barrier of Baja California. Some interchange between the two groups around the tip of Baja is possible but is not evident in the serological samples. The northern and Gulf subpopulations are separated by some hundreds of miles of ocean inhabited by the southern subpopulation with its low frequency of C-positive sardines.

Clark (1947) and Wisner (1961) have both investigated vertebral counts of sardines from the southern end of the Gulf of California; only one of these samples, 200 fish examined by Wisner, was also serologically tested. This particular sample had 16.84% C-positive sardines, typical of the Gulf subpopulation. The average count on this sample was 51.09 vertebrae. Wisner reported an average of 51.02 vertebrae for all sardines examined from the Gulf, and Clark reported

51.04. Wisner made vertebral counts on 980 fish from 10 samples of sardines serologically identified as from the southern subpopulation, finding an average of 51.36 vertebrae, and on 700 fish from 7 samples of sardines from the northern, finding an average of 51.44 vertebrae; these averages are not significantly different. Both averages however are significantly higher than that of the Gulf sardines, which are genetically different from the two subpopulations outside the Gulf.

SUMMARY

Three genetically distinct subpopulations of the Pacific sardine are recognized by the frequency of occurrence of C-positive blood type sardines. Two of these subpopulations, a northern and a southern one, live off the coast of California and the outer coast of Baja California, Mexico. The third group inhabits the Gulf of California. C-positive individuals have been found to constitute 13.6% of the northern subpopulation, 6.0% of the southern, and 16.8% of the Gulf subpopulation.

The northern and southern subpopulations have shown considerable seasonal movements, generally northward in the spring and summer with a return movement toward the south in the fall and winter. The data indicate that these seasonal movements do not result in significant interbreeding or intermixing between the two groups.

The distribution of the northern and southern subpopulations during the 1961–62 commercial fishing season was such that the data collected from the commercial catch could be related to specific subpopulations enabling us to compare age and size. The two dominant year-classes in the southern group are the 1958 and 1959 class, in the northern group the 1956 and 1957 classes. The sizes at given ages of fish from the southern subpopulation are much smaller than those of fish from the northern.

Gulf sardines have a lower average number of vertebrae (51.04) than either the northern (51.44) or the southern (51.36) subpopulations.

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Determining the Age of Young Herring from their Otoliths

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ABSTRACT

The validity of the otolith technique for aging young Atlantic herring (*Clupea harengus harengus*) of the Maine commercial fishery was established by the Petersen and known-age methods. Tests of interpretation among different observers demonstrated a reproducibility of better than 90 percent.

The study is based upon a collection of approximately 20,000 length measurements and 7,500 otoliths assembled from the catches between 1960 and 1962, and shows that the fishery is essentially a one-year-class fishery for 2-year-old herring.

INTRODUCTION

The Atlantic herring, *Clupea harengus arengus*, Linnaeus, is an abundant and valu-ble fish of the Gulf of Maine. In the coastal vaters of Maine it is harvested principally as juvenile fish, 10 to 20 centimeters long. he young fish are packed in cans and narketed as sardines.

A successful year in the Maine sardine in-ustry is predicated upon the harvest of about 3,000 metric tons of herring and the produc-ion of 2 million cases of sardines. Catches ave been as great as 71,000 metric tons in 962 and as low as 25,000 metric tons in 961. Predictions of the year-to-year avail-bility of the sardine-sized herring are much esired by the industry for managing its in-entories. Fundamental to such predictions, s well as to determining the vital statistics of e Maine herring stocks, is a knowledge of e herrings' ages.

Previous attempts to age Maine herring ave not been successful. Huntsman (1919) udied 35 samples containing 9.500 young erring from the fishery between Jonesport, laine, and Point Lepreau in the Bay of undy. He abandoned the scale method be-ause he could not distinguish winter rings early, and concluded tentatively from length equency distributions that there were both ring- and fall-spawned herring in the Bay of undy. He estimated that the growth period as from May to September, and that by the cond winter the spring-spawned fish were 5 cm long and the fall-spawned fish, 12.5 cm ng. Lea (1919) examined eleven samples of erring collected between Cape Breton Island and Gloucester, Massachusetts, and found it "strikingly noticeable" that the scales were more difficult to read than specimens from the Gulf of St. Lawrence. He considered his material too limited to permit a definite statement concerning the differences he observed in the scales. Graham (1936) concluded from a study of length measurements that the herring of Maine and New Brunswick in the Passamaquoddy Region enter the fishery when they are about 12 months old (August) and 10 cm long. He also concluded from an investigation of herring fry that spring spawning makes no considerable contribution to the herring stock. Scattergood (1952) noted that the determination of age of the Maine herring was a distinct and unsolved problem. The International Passamaquoddy Fisheries Board (1960) found a high proportion of herring scales unreadable and used total length measurements to determine the age distribution of the fishery. Subject to slight yearly variation, the fish grew to about 12 cm, total length, in their first year of life, and were 17 cm on completion of the second year. The length measurements indicated that only a small number of herring in the catch were three or more years old.

McNairn (1933) reported that Fundy herring spawn mostly in summer and fall, but referred to small numbers of spring spawners at the head of Fundy and St. Mary Bay. Scattergood (1952) stated that there were no spring-spawning herring in Maine at that time. Bigelow and Schroeder (1953) recorded that both spring- and fall-spawning herring were formerly reported in the Bay of Fundy, but that the spring spawners seemed never to have been very numerous. They considered it unlikely that there were any spring spawners in the Bay in 1953. The Bay of Fundy reports are the only recorded instances of spring-spawning that might have contributed to the Maine fishery.

The evidence presented in the reports cited above indicates that most of the herring are born in the fall, that they are exploited principally during their first 3 years of life, and that it is apparently impossible to distinguish annuli on the scales. It is evident that a reliable method of aging young herring is needed to determine the year classes in the fishery as an aid to defining growth rates and effects of fishing upon the stocks.

Otoliths have been substituted for scales in age studies of such species as the plaice, *Pleuronectes platessa* (Wallace, 1915); the hake, *Merluccius merluccius* (Hickling, 1933); and the redfish, *Sebastes marinus* (Kelly and Wolf, 1959). Lissner (1925) observed that the herring scale in several European areas often was not dependable because false or secondary rings were formed. He found that the otoliths were especially clear in 1- to 3-year-old Elbe herring and in the young age-groups of the western North Sea. He stressed the value of otolith in the age determination of young herring. The otolith method seemed worthy of examination as a technique for aging the herring of the Maine fishery, and it was the purpose of this study to evaluate its effectiveness.

THE HERRING OTOLITH

There are three otoliths in the ears of bony fishes. They function as perceptors of gravity and sound. The largest otolith, the sagitta, is employed in age determination, and the words *sagitta* and *otolith* are used synonomously in this report. The herring otolith is enclosed in a chamber of the labyrinth and lies at the base of the skull. The otolith is a laterally compressed, oval structure, formed essentially of aragonite crystals and an organic network. Anteriorly it is deeply cleft into a long ventral rostrum and a short dorsal antirostrum (Figure 1). The posterior edge is blunt and rounded, and is slightly indented at the midline. The outer (distal) surface is concave the inner (proximal) surface is convex with deep longitudinal furrow lying between tw ridges. Both surfaces taper outward in a directions to a thin edge. The margins a irregularly indented.

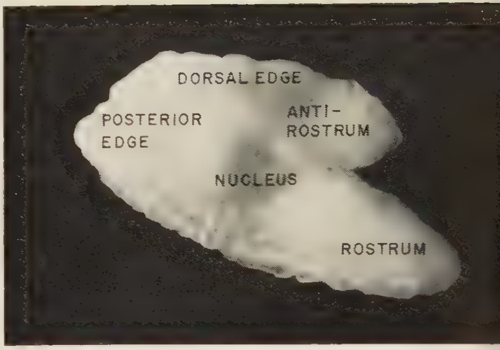


FIGURE 1.—Right otolith of a 19-cm Maine herrin (Distal aspect, photographed in dry state; the leng is 3.4 mm.)

The otolith of a 15-cm Maine herring usually 2.6 mm long, 1.5 mm wide, and 0.5 m thick. When moistened and placed distal su face upward upon a black surface in reflecte light, it appears as a crystalline structu formed of light (opaque) and dark (hyaline bands. The central area, or nucleus, is usuall hyaline and roughly circular; it may vary i diameter from 0.1 mm to 0.5 mm. The nucleu area is surrounded by a broad opaque zo which is, in turn, bounded by a narrow hy line zone. The first opaque zone may be a much as 350 microns wide as compared wit 35 microns for the surrounding hyaline zon As the herring becomes larger the differenc between the widths of the alternating hyali and opaque zones gradually decrease, but th opaque zones continue to be the more distinc

The nuclei of Maine herring otoliths a predominantly hyaline, but they vary in si and shape among individuals, and they som times vary between the right and left otolith of the same fish. In a small number of indivi uals the nucleus is partially or completely ove grown by the first opaque zone. Hyaline ot lith growth in fishes is usually called "winte growth, and opaque, "summer," althoug the time of zone formation varies amon species and, to a more limited extent, amon individuals of the same species. The nucleu

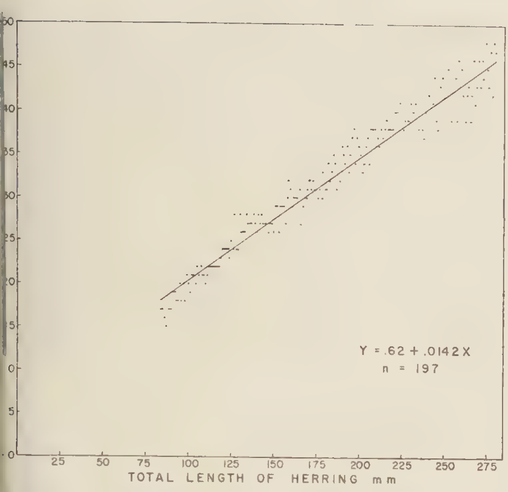


FIGURE 2.—Relationship of otolith length (*Y*) to dy length (*X*) of herring in the commercial fishery Maine. Regression line fitted by method of least uares.

the herring otolith may offer some indica- on as to whether the fish was hatched in the ring or fall. A fall-hatched herring should rm its otolith about a core of winter growth. ie otolith of a spring-hatched fish should gin with the opaque growth of summer.

Gray (1951), describing the comparative atomy of the labyrinth, cites the direct re- ionship between the size and age of a fish d the size of its labyrinth as a characteristic bony fishes. For herring in the Maine mmercial catch the otolith length increases direct proportion to the body length (Fig- 2). Thus any persistently recurring an- al change in the otolith structure will form record of age.

MATERIALS AND METHODS

All herring described in this report, with exception of aquarium specimens, were lected from the commercial fishery of ine. The standard sample consisted of 100 more herring. The total lengths (tip of er jaw to the longest ray of the caudal fin a natural, uncompressed position) in milli- ters of all specimens were recorded, and liths were dissected from 50 fish in each mple. The otoliths were stored dry in ked 6- by 50-mm culture tubes numbered ially to correspond with the length records.

The collection was divided among three years as follows:

YEAR	NUMBER OF SAMPLES	NUMBER OF HERRING	NUMBER OF OTOLITH PAIRS
1960	20	2,407	984
1961	43	7,110	2,124
1962	87	13,950	4,351
Totals	150	23,467	7,459

The frequency and place of sampling were wholly dependent upon the fishery. Nearly 90 percent of the samples were taken from stop-seine catches. Weirs and purse seines accounted for the remainder. These fishing methods have been described by Scattergood (1949).

The otoliths were prepared for examination by placing them distal surface upward in the depression of a black culture slide and covering them completely with distilled water. Thirty seconds of immersion brought out the zoned appearance for examination under a low power (10× to 30×) "zoom" dissecting microscope. Summer zones were counted on the dorsal portion of the otolith. Otoliths were measured with a compound microscope equipped with a Leitz Ultropack Incident Light Illuminator and ring condenser.

Six percent of all herring collected had a single crystalline otolith. Zonation was either poorly defined or missing in such otoliths, and only the normally growing member was used for age determination. The occurrence of two crystalline otoliths was very rare in herring from the natural environment; it occurred only about once in every 2,000 specimens collected. Specimens with paired crystalline otoliths were discarded as illegible.

Otolith growth under aquarium conditions was determined from small samples of a group of herring, initially of 10 to 12 cm total length, held for 30 months in a tank of circulating seawater. The tank was 6 meters in diameter and 1 meter deep. The aquarium fish were all taken at the same time, and are presumed to have been derived from a naturally formed school.

The validity of the otolith method for immature Maine herring has been tested by (1) the Petersen method (length frequencies), (2) the "known age" method, and (3) the assessment of variation in reading that might be expected from different readers.

The Petersen method utilizes the tendency of length observations to group in approximately normal curves about a central value according to age. The method has several limitations:

1. It is applicable only to young fish in their first three or four years of life.
2. The spawning season must be relatively short and must occur but once a year.
3. Large samples of successive year classes of young fish are required.
4. The age of most of the fish is determined, but the method cannot be used to age individuals. Overlapping frequency polygons may mask fast- and slow-growing fish of the different year classes.

The small herring of the Maine fishery are especially suited to the Petersen method because they are in early years of life and because all existing evidence points to the majority of them having hatched during a single season: autumn.

The collection of otoliths used in this report to determine lengths at age was examined by two observers. Opaque, or "summer" zones were counted rather than hyaline "winter" rings because the opaque zones are broader and more easily seen. Observers were provided with complete sampling data to assist them in making year class assignments. If the two independent readings failed to agree exactly in year class assignment, the specimen was discarded as illegible. The term, "year of life," when used here, is an approximation of chronological age. A herring of the 1960 year class sampled during the 1962 fishing season would be considered in its second year of life, or approximately 2 years old. Both the length-frequency distributions and the lengths at age determined from the otoliths were grouped in monthly units and plotted on a percentage basis at the midpoints of 1-cm class intervals.

The aquarium samples consisted of 22 herring in October 1960 and March 1961; 24 herring in August 1961; 9 herring in February 1962; and 1 herring in April 1963. The otoliths were interpreted in the same way as those of fish from the natural environment.

TABLE 1.—*Age composition of the Maine herrin catch for the years 1960, 1961, and 1962 base upon age determinations from otoliths*

Year	Year class	Percent of total catch	Year of life
1960	1959	10	First
	1958	84	Second
	1957	6	Third
1961	1960	22	First
	1959	54	Second
	1958	23	Third
	1957	1	Fourth
1962	1961	3.0	First
	1960	96.0	Second
	1959	0.6	Third
	1958	0.4	Fourth

To determine the variation that could b expected among different interpreters of th Maine otolith samples, a panel of five observer was formed. Each observer was familiar wit the herring, its otolith, its biology, and th importance of age studies. Two tests were de vised. They were based upon a collection o 1,500 otoliths taken in monthly units durin 1 year. Ten pairs of otoliths were draw randomly from each monthly unit and marke with code numbers. There was no sequenc in the code numbers that would indicate th season of sampling.

For the first test the otolith pairs wer thoroughly mixed. Each observer was aske to interpret the sample and record the follow ing observations: (1) Nucleus type (opaqu or hyaline), (2) Number of opaque zones (3) Margin (opaque or hyaline), and (4 Year of life. No information was given con cerning the date of capture nor the size of th fish.

The second test was a replica of the firs except that readers were provided with th date of capture and the length of the fish an were asked to use an artificial (September 1 birthdate in assigning the fish to its year o life. For all purposes other than the test de scribed here, the fishing season of captur and the year class have been used for dete mining year of life. There was an interval o four weeks between the two tests, and ob servers taking the second test could not refe back to their observations on the first test All interpretations were made individuall and were considered final when completed No opportunity was provided for the observer

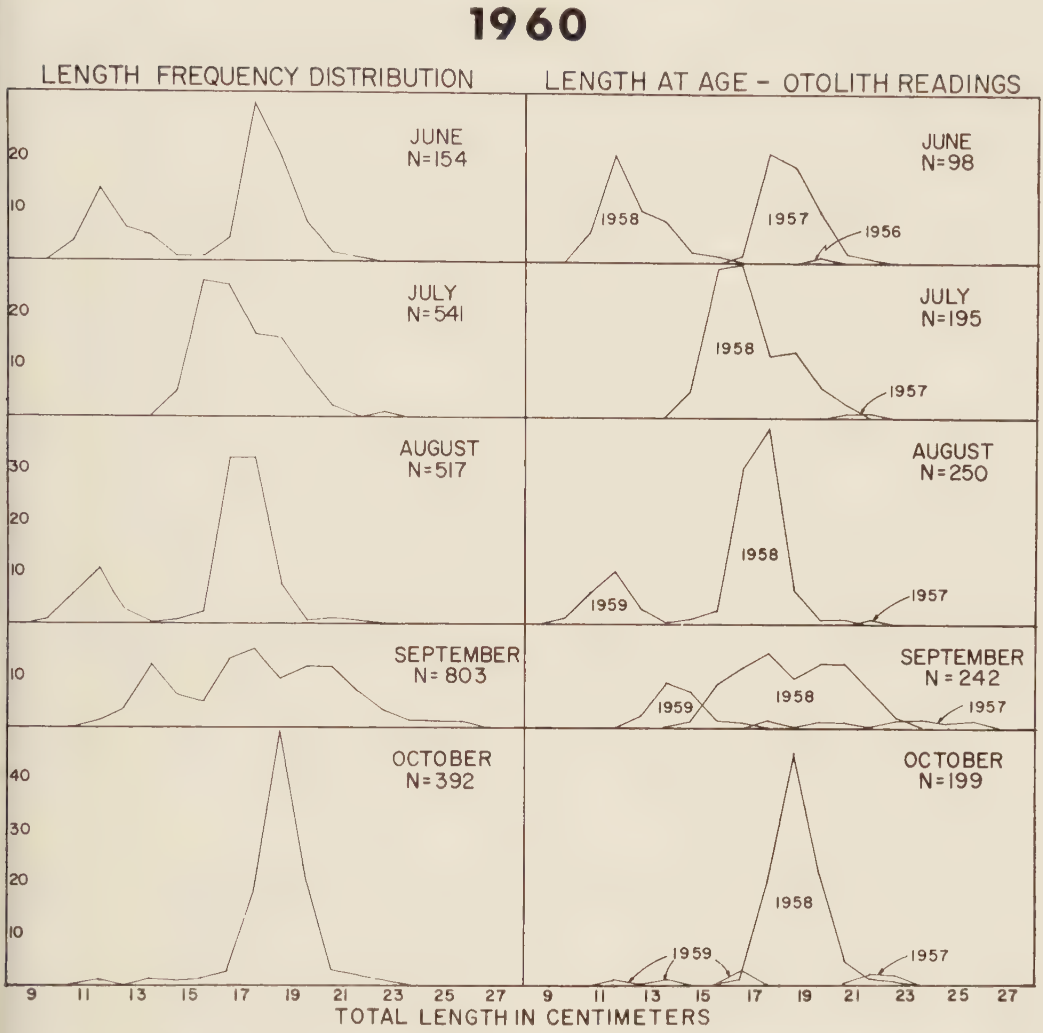


FIGURE 3.—Comparison of length-frequency distributions and the distributions of lengths at age from olith readings of herring from the 1960 fishery in Maine.

consult among themselves and revise their adings.

To trace progressive seasonal changes in e otolith margin, herring were collected in onthly units for 1 year from the Eastport, aine, fishery. The purpose of the study was learn from the natural environment when e otolith forms opaque and hyaline growth.

RESULTS

The frequency polygons formed by the tersen distributions and the lengths at age om otolith readings are homologous. The polygons for 1960, 1961, and 1962 are shown in Figures 3, 4, and 5. The agreement between the two methods indicates that the majority of the otolith interpretations are correct. Figure 6 pictures otoliths with one, two, and three summer zones sampled during the autumn of 1962, and typifies specimens assigned to the 1961, 1960, and 1959 year classes, respectively. Herring in the second year of life formed the largest portion of the catch during each year of the study (Table 1).

Four percent of the otolith pairs were discarded because they were illegible. The chief

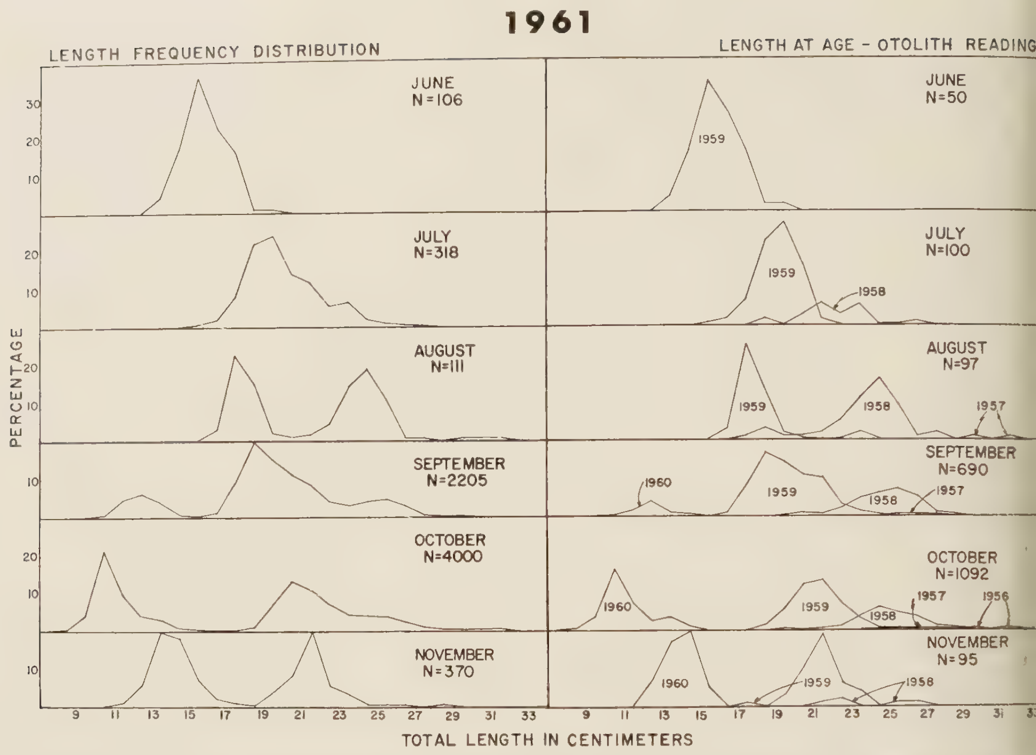


FIGURE 4.—Comparison of length-frequency distributions and the distributions of lengths at age fro otolith readings of herring from the 1961 fishery in Maine.

cause of illegibility was the splitting of opaque zones into fine white striations, a condition generally referred to as a "splitting" of the summer zone. Less important causes of illegibility were fractures, stains, and the rare occurrence of paired crystalline otoliths.

The otoliths of herring held in an aquarium became crystalline at a much higher rate than did those of fish from the natural environment, but they provided additional evidence that one opaque zone is formed each year. Often the crystallinity was only partial, as in Figure 7, and the number of zones could interpreted. After 10 months of aquariu life, nearly half the herring exhibited som crystallinity in one otolith; after 16 month partial crystallinity appeared in both otolith of 60 percent of the fish. The increase in si of the aquarium herring and the addition opaque growth zones are shown in Table 2

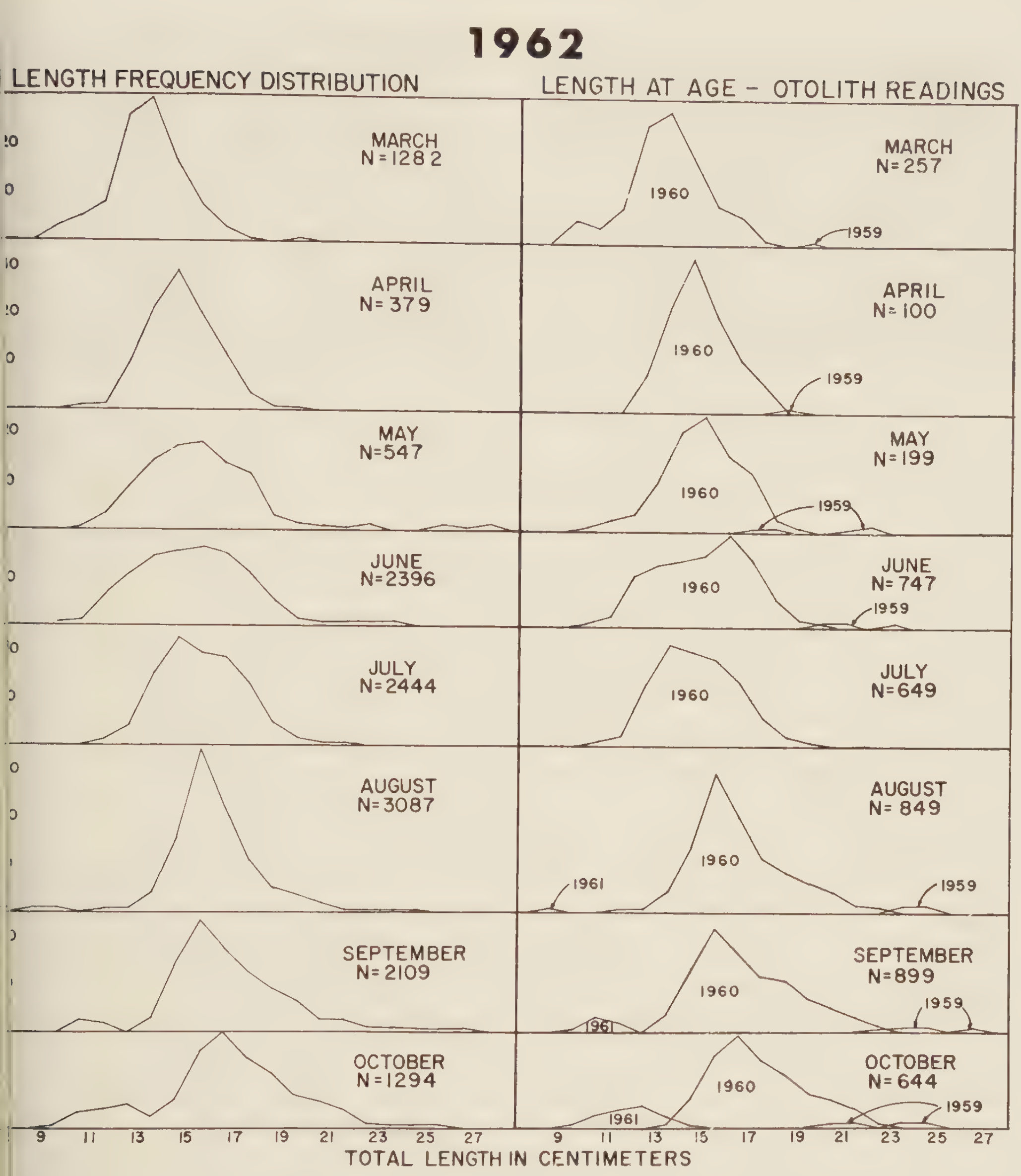
The otolith interpretations made by five o servers upon the same group of herring a compared in Table 3. The most importa feature in age determination is the agreeme

TABLE 2.—*Increase in number of opaque zones of aquarium-held herring*

Date	Number of herring	Mean length and range (cm)	Number of opaque zones
October 1960	22	10.9 (10.2–11.8)	1
March 1961	22	11.9 (10.8–13.3)	1
August 1961	24	15.8 (13.6–17.6)	2
February 1962	9	18.1 (15.3–20.1)	2
April 1963	1	21.5	3

TABLE 3.—*Comparison of otolith interpretations ma by five observers*

Interpretation	Percentage agreeme	
	Test No. 1	Test No.
1. Number of opaque zones	88	97
2. Type of margin	26	51
3. Year of life	27	97
4. Nucleus type:		
Hyaline	69	68
Opaque	0	0



URE 5.—Comparison of length-frequency distributions and the distributions of lengths at age from h readings of herring from the 1962 fishery in Maine.

the number of opaque zones. The in- e in agreement from 88 to 97 percent on econd test was due to the ease in evalu- marginal growth that the observers de- from knowing the sampling date. For ple, an early summer otolith may have a slender margin of opaque growth. If does not know the sampling date, he attribute the opaque-appearing margin to ion of the crystalline edge and so be in error by one zone. A knowledge of the sampling date also aids in the assignment of a fish to its proper year class. A late August otolith with a hyaline edge may resemble closely a hyaline-edged otolith from the same year class taken the following June. If one knows the sampling date he can avoid an error that would place the fish in the wrong year class.

The otolith margin is a difficult quality to

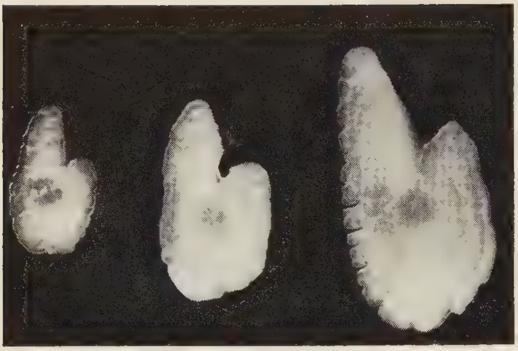


Figure 6.—Left otoliths of herring from the Maine commercial fishery showing one, two, and three summer zones. (Photographed in moist state.)

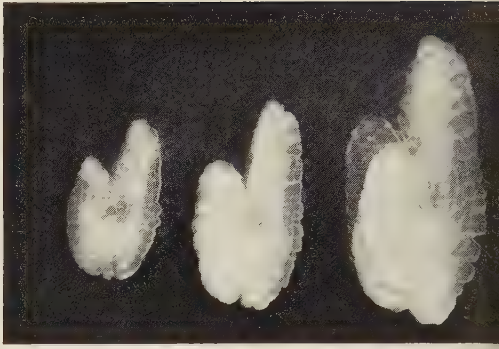


Figure 7.—Right otoliths with one, two, and thr summer zones from herring maintained in an aqua ium for 30 months. (Photographed in moist state.)

assess. In those instances in which readers did agree upon the type of marginal growth, they were, with one exception, unanimous in selecting opaque edges in July and August and hyaline edges during the other months of the year. The low percentage of agreement emphasizes the necessity of providing readers with the dates of sampling. All of the proportionately low agreement upon nucleus types was based upon hyaline nuclei. There was no agreement on opacity.

The progressive seasonal changes in the otolith margins of the monthly samples from Eastport, Maine were evaluated by two observers. The margins were often difficult to interpret. The observers were most confident in cataloguing the hyaline growth appearing in late spring and the opaque growth formed by midsummer. Otoliths that appeared to be in transition from one growth type to another were especially difficult to assess. The observers concluded that (1) the formation of the slender hyaline zone is a long slow process that begins in late summer or early autumn and continues well into the following spring. Even in June over 60 percent of the otoliths continue to show a hyaline edge; (2) the opaque zone is formed rapidly during July and August; and (3) the herring otolith forms one opaque and one hyaline zone each year.

DISCUSSION

The cause of the zoned appearance in otoliths is unknown. Immerman (1908) ascribed zonation in the plaice otolith to the optical effect produced by distortion of the crysta line structure. For the hake otolith, Hicklin (1931) hypothesized that the ringed structur was caused by the varying thickness of th organic lamellae containing the minute (micron by 40 micron) interlocking crysta of aragonite. Dannevig (1956) conclude from a chemical analysis of the cod, *Gadu morhua*, otolith that transparent zones contai inorganic compounds (essentially calcium ca bonate and calcium oxide) only, and tha opaque zones contain both the calcium compounds and a protein, conchiolin.

A measure of the accuracy with which th appearance of the nuclei of herring otolith can be attributed to spring or fall hatchin of the herring is given by Einarsson (1951 Using the descriptive terms "opaque nucleus and "large well-defined hyaline nucleus" h was able to classify 85 percent of 390 adu Norwegian spring spawners, and 67 percen of 300 immature Icelandic summer spawner The intergradation between opaque and hy line types impeded further strict classificatio The Norwegian adults were classified a spring spawners according to maturity stag and the immature Icelandic herring wer classified as summer-spawned herring b mean vertebral count. Einarsson assume that degree of maturity was a true index t race and that there was no crossing-ove among the two races at spawning time.

Other evidence concerning the herring nucleus has been presented by Birtwistle an Lewis (1923). They described the transparen nucleus of Irish Sea herring as strengthenin

e assumption that herring whose otoliths
ve transparent nuclei are fall spawned, but
l not have spring-spawned herring for com-
rison. Lissner (1925) found a hyaline area
vays present in Norwegian spring spawners.
described it as very minute, often hard to
, and surrounded by a strong opaque zone.
concluded that fall herring have a wide
aline center, and spring herring a very
all one. Lissner hypothesized that the size
the large hyaline center decreases in pro-
rtion to the lateness of the season in which
fish is hatched. Parrish and Sharman
956) cited the nucleus characteristic as
isfactory for classifying the majority of
ring in the spring- and autumn-spawning
oups of the North Sea area. They did not
nsider it suitable for separating fish that
spawned in different areas during the
ne season.

The edge of the otolith is especially diffi-
t to interpret if the herring are collected
ring the marine winter when the addition
a slender hyaline margin is expected. The
ficulty appears to be caused by halation,
spreading of light beyond its proper
undary within the crystalline structure.
twistle and Lewis (1923) observed that it
ms necessary for the clear winter ring to
surrounded by an opaque summer zone be-
e it can be definitely discerned. They
nd that in some cases it "almost looked"
if late fall otoliths were hyaline-edged.
sner (1925) reported that several times he
a clearly defined hyaline ring in his fall
erial. The difficulty of interpreting edges
compounded by the fact that all herring
liths cannot be expected to change simul-
eously from one growth type to another.

Based upon an analysis of about 20,000
ring and 7,500 otolith pairs collected from
commercial herring fishery in Maine be-
en 1960 and 1963, it is concluded that:

The otolith technique is a valid method for aging the herring of the Maine fishery. Its validity has been established by the Petersen and "known-age" methods.

The otolith method is very constant, or reproducible, among different observers. A test of five observers indicated that different readers will produce identical age analyses for over 90 percent of the herring.

3. The herring fishery of Maine depends principally upon a single year class of fish in their second year of life.

ACKNOWLEDGMENTS

Prior to the commencement of this study, Mr. Basil Parrish of the Marine Laboratory, Aberdeen, Scotland, gave me his evaluation of some otoliths collected from the Maine fishery; his comments have been very helpful. Mr. Frank E. Perkins supervised the studies of herring in the aquarium environment.

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A Tag for Young Herring

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A TAG FOR YOUNG HERRING

by John E. Watson, *Fishery Research Biologist , U. S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine.*

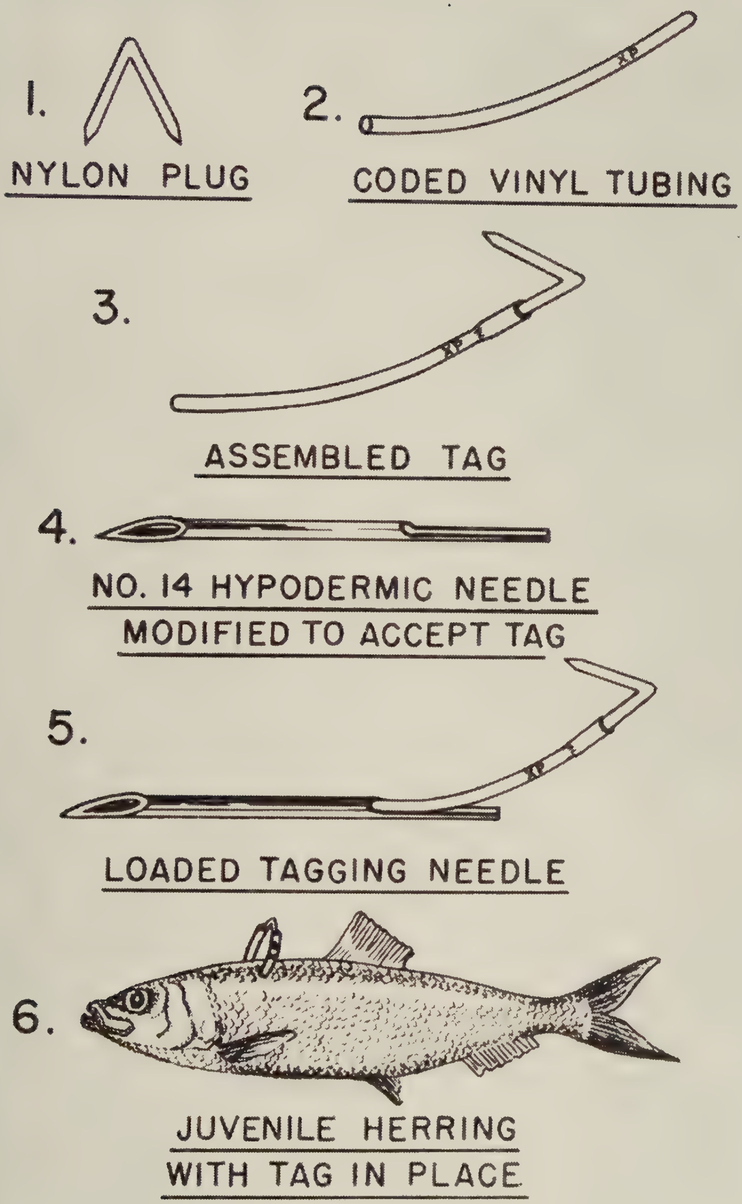
External fish tags are a compromise between maximum visibility to the finder and minimum impairment to the fish. The young herring of the Maine coast, called sardines when they are 5 to 8 inches long, exemplify some of the problems one can encounter in designing a fish tag. These fish are most delicate; their skin and scales are easily dislodged, and a herring that loses half its scale covering is certain to die. The first requirement for a tagging, then, is that it involve the least possible handling of the fish.

A second problem is posed by the vigorous handling that the fish will undergo when recaptured. It will be pursued in a net, pumped through a descaling machine, salted in the hold of a boat, transported to a factory, and then pumped once again onto an endless belt for movement to the terminal processing area. Since the processor is the prime source of tag recoveries, the tag must be so strongly attached as to withstand dislodgment during the trip from ocean to canning factory.

A third problem is to insure the likelihood of the tagged fish being found after reaching the factory. To be quickly perceived the tag must be external and of a color that will show up vividly among a group of herring. There is also a problem in recovering tags. The herring are so numerous that in one year the commercial harvest of the northwest Atlantic exceeds in numbers the human population of the world. Any tagged herring is bound to have a tremendous number of untagged companions, and to improve the odds for recovery a herring tag must be suited to quick attachment so that large numbers of fish can be tagged. Finally, there are a number of inherent problems that pertain directly to the herring as a foo fish. Although a tagged fish is unlikel to pass through the stringent inspection routines of a sardine factory, tag made of metal, radioactive materials or chemically active substances ar considered undesirable. Obviously a soft inert non-toxic material is needed Color should remain fast against the chemical action of seawater, and colo markings should hold their legibilit through a variety of changes.

In searching for a suitable tag, tried many methods: barbs, darts, tattoos, electric brands, dies, and even pressure-sensitive tapes. For one reason or another none of these proved satisfactory in aquarium tests.

The tag that performed best in aquarium tests was basically a teardrop-shaped loop of yellow polyviny chloride tubing passed through the heavy back muscle of the herring midway between the dorsal fin and the cranium. This location seemed the least subject to the movements of the swimming fish and therefore an area likely to heal quickly. Polyvinyl chloride, usually called PVC, is soft, flexible, inert, and non-toxic, and can tolerate a wide range of temperature Even after a year's immersion in seawater there was no perceptible chang in the tag. To seal the tag and form the teardrop after the PVC had been passed through the dorsal muscle with a hypodermic needle, I devised a V shaped nylon plug which is held place by friction. In precise detail, PVC tubing was 2-⅛ inches lon the outer diameter was 0.051 inche the inner, 0.025 inches. The nylo plug was 0.045 inches in diamete and was formed of a 1-inch length nylon rod sharpened at the ends an bent with heating to an angle of abou 45°. The prototypes of the tag wer made by hand, and when aquarium tests offered good hope for success



Maine Sardine Tag

the tag was subjected to sea tests. Several thousand tags were made commercially; code letters were engraved in them and the engravings filled with black vinyl ink. For inserting the tag in the herring a No. 14 hypodermic needle was chosen. The after end was ground off so that the tag would slip easily into the needle.

The first sea tests were made in 1960. Young herrings were purchased from fishermen at various areas in Maine, the tags were attached, and the fish released. The sea tests showed that tagged herring could survive in the marine environment. The averag recoveries were about 2%, althoug occasionally the rate was as high 5%. Fishing for herring is heaviest the dark of the moon, and most of th recoveries were made within one lun cycle. A few tags were recovered aft a year in the ocean.

The herring tag provides a mea for determining the herring's abun dance, movements, and growth. N that the tag's qualities have been as sessed in extensive sea trials, it w be used for precision studies of th population.

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Fractionated doses of X-radiation: A preliminary study of effects on teleost embryos

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Doses of x-radiation, fractionated during the first six days of embryogenesis, produced a delay in the rate of development, a decrease in survival, and a decrease in the percentage hatch of *Fundulus heteroclitus* eggs. These effects became more prominent as the dose was increased.

1. Introduction

There have been few, if any, investigations into the effects of fractionated doses of radiation on embryonic development, especially in teleost fishes. Vertebrates which have demonstrated a greater tolerance to fractionated doses of radiation than for acute doses of similar magnitude have in the main been adult mammals whose changes in sensitivity with age were not considered to be a critical factor. It has been found, however, that fish embryos (and those of other vertebrates also), when exposed to acute doses of radiation at different developmental stages, display a rapidly decreasing sensitivity to radiation with ncreasing age (Allen and Mulkay 1960 a, Welander 1954 a, Bonham and Welander 963). Just what effects would result if embryos were exposed to fractionated doses of external radiation, a situation more closely simulating one that might occur in nature, remains to be investigated.

It is generally agreed that there is a trend for radiation-sensitivity to decrease with increasing age, and that this trend is more prominent in embryos than in adults. According to Welander (1954 a), trout embryos, irradiated in the one-cell stage, had an LD_{50} (at hatching) of 78·3 r, while those irradiated in the late germ-ring stage had an LD_{50} (at hatching) of 735 r. Welander, Donaldson, Foster, Bonham, Seymour and Lowman (1949), also determined that the LD_{50} 30 days) for adult trout was 1500 r.

The purpose of this paper is to present some results of a preliminary investigation into the effects of fractionated doses of ionizing radiation on the rate of morphogenesis, hatchability, and survival of embryos of the killifish, *Fundulus heteroclitus* (Linnaeus).

2. Methods

Gametes from male and female *Fundulus* were stripped into clean 4 in. ngerbowls containing 50 ml of Millipore-filtered seawater and the zygotes were lowed to develop to the 2–16 cell stage. During this developmental process, the eggs were washed several times in sea water and were placed, about 50 in each group, in round plastic dishes containing only enough water to cover the eggs.

As soon as the 2–16 cell (median 8 cells) stage of development had been reached by the eggs within each group, they were irradiated with a 100 kvp x-ray machine. The machine was operated at 5 mA, giving a dose-rate of 100 r per minute as measured in air with a Victoreen thimble chamber (250 r capacity). One millimetre of aluminium and the inherent filtration of the x-ray tube, which was equivalent to 0·5 mm of copper, filtered out the soft emissions.

The following fractionated doses were administered to the different groups of eggs once every 24 hours for six consecutive days: 100, 250, 500, 1000 and 2000 r, to give cumulative doses of 600, 1500, 3000, 6000 and 12000 r, respectively, by the end of day 6. The control group of eggs, except for radiation exposure, was treated in the same manner as the eggs in the irradiated groups.

After irradiation, each group of eggs was returned to separate finger-bowls and maintained at a temperature of 20° ± 0·5°c in a B.O.D. incubator. A 12-hour photoperiod was provided by an automatic timer connected to a 7·5 w incandescent bulb. These time and temperature factors were selected, rather than the more usual 25°c or room temperature in studies on *Fundulus* embryos, because they existed in nature at the beginning of the experiment. Moreover, at 20°c, the eggs develop at a slightly reduced rate, which allows more time for observation. Water was changed daily to reduce the possibility of bacterial and protozoan infestation.

All eggs were examined once daily with a dissecting microscope until either hatching or death occurred. During the first six days, observations took place immediately prior to irradiation. Throughout this observation period Oppenheimer stages of development in *Fundulus heteroclitus* (Oppenheimer 1937) were recorded as closely as possible. Criterion for death was either disintegration of the yolk-sac, resulting in egg opacity in the pre-heart stages, or cessation of heart-beat in later stages of development.

Oppenheimer stages were recorded to determine changes in the rate of development of the eggs as affected by radiation. It should be noted that x-radiation causes such specific organ effects (Solberg 1938 a) that the stages named herein are, necessarily, of a general nature and depend on specific organs that develop in a predetermined sequence. In some instances, especially in the higher dosage groups, certain organs failed to develop altogether, while others, developing in the subsequent course of differentiation, evolved in a normal manner. In such specimens, the more advanced organ was used to determine the Oppenheimer stage. In cases of rudimentary organ development, these organs were recorded as having developed, but were used in the determination of Oppenheimer stages only when positive identification of the rudiment could be made.

The following parameters were recorded throughout the course of the experiment as criteria for radiation effects: the rate of development for each egg, embryo-survival, and egg-hatch.

3. RESULTS

3.1. *Rate of development*

X-radiation, delivered in fractionated doses, had a retarding effect on the rate of development of *Fundulus* embryos (figure 1). Each day indicated in figure 1 depicts the median rate of development for each group of eggs. The median represents that stage which divides a group so that one-half or more of the eggs are equal to, or less than, the median in development, and one-half or more are equal to or greater than it (Croxton 1953). The higher the dose the more retardation in rate of development was evident with the exception of one overlapping point in the younger stages. This effect became more prominent after day 6 when organ differentiation began. The most advanced stage shown in figure 1 was stage 31 which is that Oppenheimer stage immediately prior to hatching. Stage 32, the hatching stage, is discussed elsewhere.

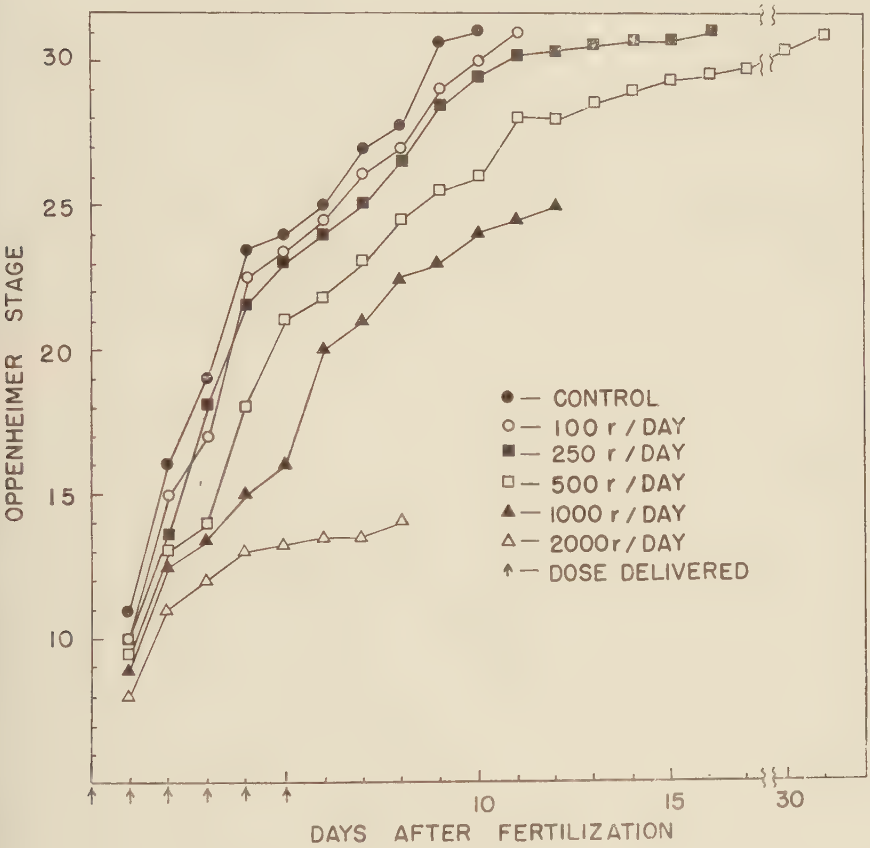

Figure 1. Rate of development in *Fundulus* embryos after exposure to fractionated doses of x-radiation.

Formation of specific organs in the control eggs followed the sequence set forth by Oppenheimer; however, the rate of development was retarded slightly from the rate shown by embryos developing at room temperature. The slower rate of development due to low temperature has been documented for *Fundulus* by Solberg (1938 b) and has been shown to have no deleterious effect on the normal sequence of embryonic differentiation at 20°c.

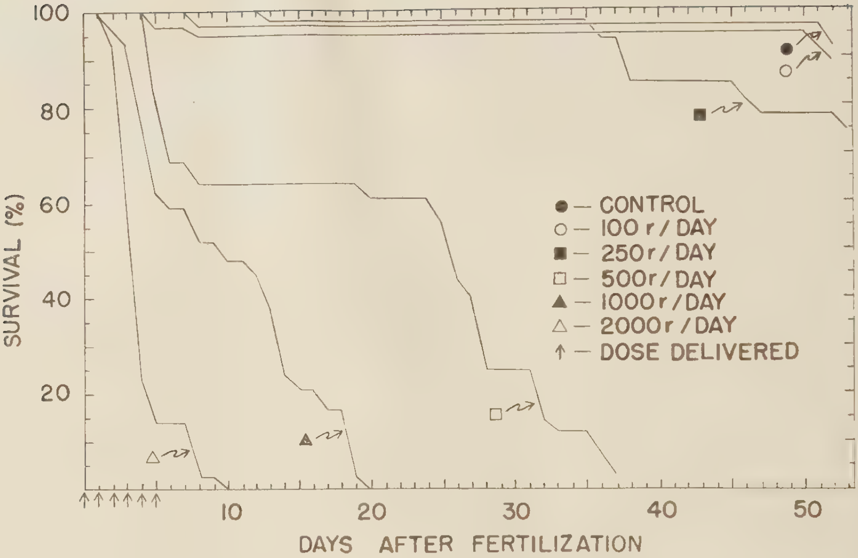

Figure 2. Survival of *Fundulus* embryos after exposure to fractionated doses of X-radiation.

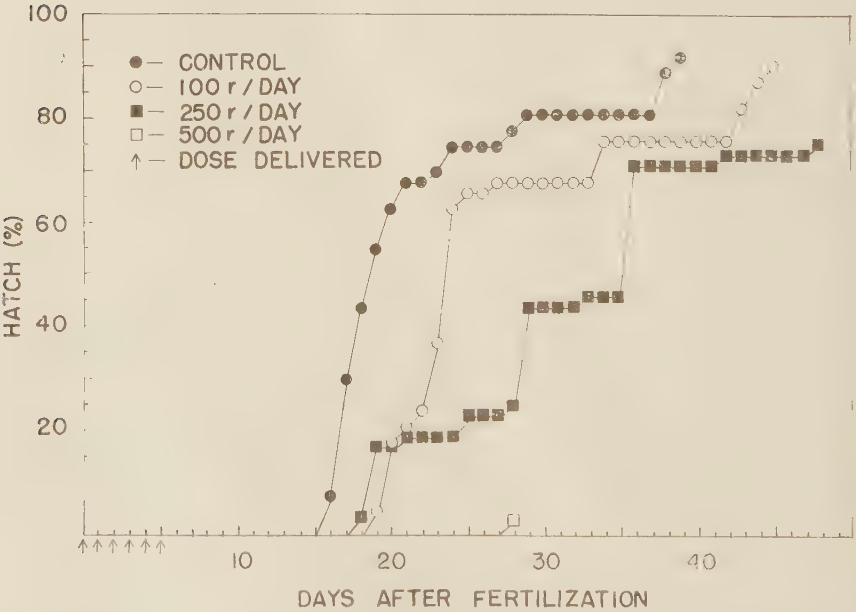

Figure 3. Cumulative hatch of *Fundulus* eggs after exposure to fractionated doses of X-radiation.

3.2. *Survival*

Fundulus embryos demonstrated a remarkable ability to survive comparatively high doses of radiation when these doses were fractionated at one day intervals for six days. This capacity was evident even though the eggs were undergoing a rapidly decreasing radiosensitivity with increasing age. Doses of 100 r per day (600 r cumulative) produced no appreciable increase in mortality over that of the controls, while doses of 250 r per day (1500 r cumulative) produced only 25 per cent mortality (figure 2).

3.3. *Hatch*

Radiation, delivered in fractionated doses, had an effect both on the percentage of embryos hatching and on the time of initial hatch (figure 3). These doses had a delaying effect on the time of initial hatch (Oppenheimer stage 32), and this delay is reflected as an extension of figure 1. Doses of 100 r per day and 250 r per day caused a delay of three to four days in the time of initial hatch, while 500 r per day produced a delay of 14 days (figure 3).

All doses used in this experiment had an effect on the percentage hatch, with the exception of the 100 r per day dose. This dose produced no appreciable decrease in hatch over that of the controls, while 250 r per day allowed 75 per cent hatch (figure 3).

4. DISCUSSION

Various investigators have noted a tendency for radiation to retard the rate of development in embryos (Allen and Mulkay 1960 b, Bonham and Palumbo 1951, Bell and Hoar 1950, Solberg 1938 a), and Rugh and Clugston (1955) observed this phenomenon frequently during their studies with *Fundulus*. There is evidence that this retardation in the rate of development begins on the cellular level by a suppression of cell-division or an increase in the interval between divisions (Giese 1947, Neifakh and Rott 1958). The results presented in figure 1 exemplify this finding in that, after the initial radiation, the rate of development proceeded at a rather uniform pace for several days in keeping with the change shown by the controls. This uniformity persisted until organ differentiation began. This would indicate that cell-division, in the interval of rapid mitotic activity, was either suppressed completely (as in the higher-dose groups) or retarded for a given period of time.

Welander (1954 b), in his study on trout, found no appreciable effect on hatching time due to radiation. Corbella (1930), however, found that the hatching period was prolonged by increasing doses of X-rays in trout; and Hinrichs (1925) demonstrated a similar delay in hatching in *Fundulus* using ultra-violet radiation. The present results show not only that a longer time is required for initial hatch due to irradiation, but also that a delay occurs in the time required for all eggs to hatch.

In this investigation embryos, whether irradiated or not, lived within the chorion for extended periods of time. This finding was not surprising, in that Milkman (1954) was able to control the hatching time in *Fundulus* by controlling the oxygen-content of the water. Other factors, such as the presence or absence of a hatching enzyme, also control hatching (Armstrong 1936). The failure of this enzyme to act, whether radiation-induced (as suggested by Rugh and Clugston 1955), or genetic (as suggested by Farris 1960), could produce a lengthy survival within the chorion. While only 5 per cent of the control embryos died within the chorion after reaching the hatching stage, the irradiated embryos lived for extended periods of time in appreciable numbers without hatching (table). These results, while inconclusive, indicate that 100 r per day for six days caused no observable effect on the hatching enzyme or the cells that produce it, while 250 r per day and 500 r per day both caused an appreciable reduction in the number of embryos hatching.

Group	Per cent of group reaching stage 31	Per cent of group hatching (stage 32)	Per cent of group apparently with no active hatching enzyme
Control	97	92	5
100 r/day	95	90	5
250 r/day	96	75	21
500 r/day	25	3	22
1000 r/day	—	—	—
2000 r/day	—	—	—

Per cent of embryos in each group reaching Oppenheimer stages 31 and 32.

5. SUMMARY

Embryos of the teleost *Fundulus heteroclitus* were exposed to fractionated doses of X-radiation during the first six days of development. Doses delivered in this manner produced a retarding effect on the rate of development of the eggs. With the exception of the lowest dose used (100 r per day), all doses produced a progressive decrease in survival with increase in dose. A definite delay in the time of initial hatch and a decrease in the per cent of embryos hatching was also a result of X-radiation.

Des embryons du téléoste *Fundulus heteroclitus* ont été exposés aux doses fractionées d'irradiation aux rayons X pendant les premiers six jours de développement. Des doses appliquées de cette façon produisent un effet de retard au degré de développement des oeufs. Selon la dose plus basse (100 r le jour) toutes les doses produisent une diminution progressive de survivance avec l'accroissement de dose. Les résultats de l'irradiation aux rayons X étaient un retard du temps distinct de l'éclosion initiale et une diminution de pourcentage d'embryons éclus.

Embryonen des Teleosts *Fundulus heteroclitus* waren während der ersten sechs Entwicklungstage fraktionierten Dosen von Röntgenbestrahlung ausgesetzt. Die angewandten Dosen wirkten verzögernd auf die Zeit der Ei-Entwicklung. Mit Ausnahme der geringsten Dosis (100 Röntgen pro Tag) verursachten alle anderen Dosen einen zunehmenden Abfall der Überlebens-Kurve mit zunehmenden Bestrahlungswerten. Eine deutliche Verzögerung in der anfänglichen Brutzeit und eine prozentuale Verminderung der ausbrütenden Embryonen war eine Folge der Röntgenbestrahlung.

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iesapeake Science Vol. 5, No. 3, pp. 151–152 Fall, 1964

nother Record of Incomplete Ambicoloration in the ummer Flounder, *Paralichthys dentatus*

BSTRACT: A specimen of the summer flounder, *ralichthys dentatus*, exhibiting incomplete ambi- loration was recently caught off North Carolina. he capture of this fish supports the suggestion at identical genetic factors or environmental mbinations may cause the phenomenon.

An incompletely ambicolorate summer flounder, *ralichthys dentatus* (Linnaeus), total length 275 m, standard length 230 mm, weight 187 g, was ught on 18 September 1963, by the commercial wler "C. G. Austin" while fishing off Beaufort et, Carteret County, North Carolina. The specin is in the fish collection of the Bureau of mmercial Fisheries Radiobiological Laboratory, aufort, North Carolina.

This flounder has abnormal pigmentation on proximately 65% of its blind side, and has llated spots symmetrical to those on the eyed e (Fig. 1). There is a partially pigmented transin zone between the colored and non-colored as. This specimen fits into the category of complete ambicoloration" as described by Daw- (1962), since no other visible anomalies are sent.

This heterosomate apparently represents the n record of abnormal coloration, and the 5th ord of incomplete ambicoloration in *P. dentatus*. addition, the present specimen is the 4th record an anomalous *P. dentatus* from North Carolina. Dawson (1962) lists nine definite records of abnormal coloration in this species; on p. 140, however, he records one taken in South Carolina waters and lists it as the 9th record.

Comparison of Fig. 1 with those shown by Dawson (1962), Hussakof (1914), and Gudger (1936), reveals a marked similarity in the extent and distribution of blind side coloration. The addition of this specimen to the records strengthens Dawson's suggestion that identical genetic operants or combinations of environmental conditions prior to metamorphosis cause this particular pattern of partial ambicoloration.

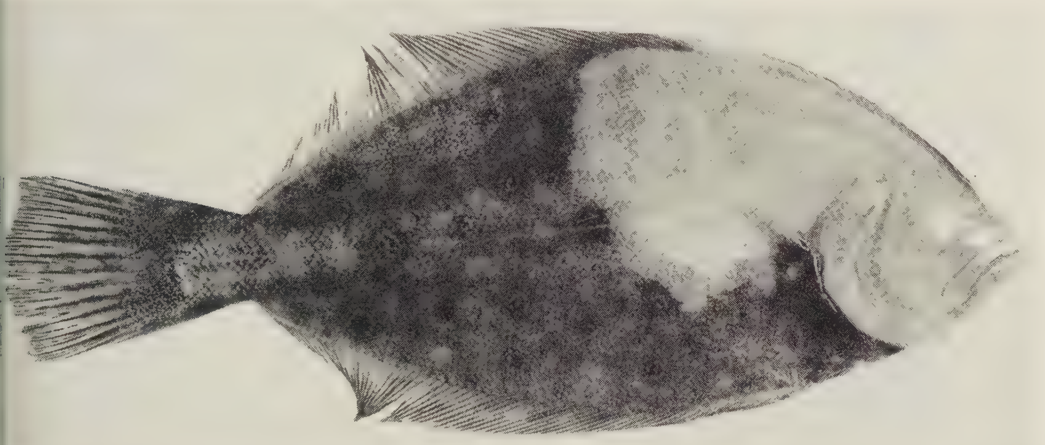

Fig. 1. Right side of a partially ambicolorate *Paralichthys dentatus*. Total length 275 mm.

The authors wish to thank Mr. Frederick Clark for making this specimen available.

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Radiobiological Laboratory,
Beaufort, North Carolina

Eudorellopsis deformis (Kroyer, 1846). In American waters reported from to Long Island in depths of ca. 2-100 meters. Adult size 4-5 mm.

Lamprops quadriplicata S. I. Smith, 1879. Occurs from Newfoundland to s England, in depths from ca. 2-150 meters. Adult size 8-9 mm.

Leptocuma minor Calman, 1912. Occurs from Gloucester, Mass. to Woods Ho of ca. 2-100 meters. Adult size 6-7 mm.

Leucon americanus Zimmer, 1943. A brackish water species reported from and Chesapeake Bay. Adult size 4-5 mm.

Oxyurostylis smithi Calman, 1912. A euryhaline species, Maine to Louisi surface to 20 meters. Adult size 6-7 mm.

Petalosarsia declivis (G. O. Sars, 1864). In American waters occurs fro tic to Buzzards Bay, in 20-200 meters.

*Not in key.

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Plate 13

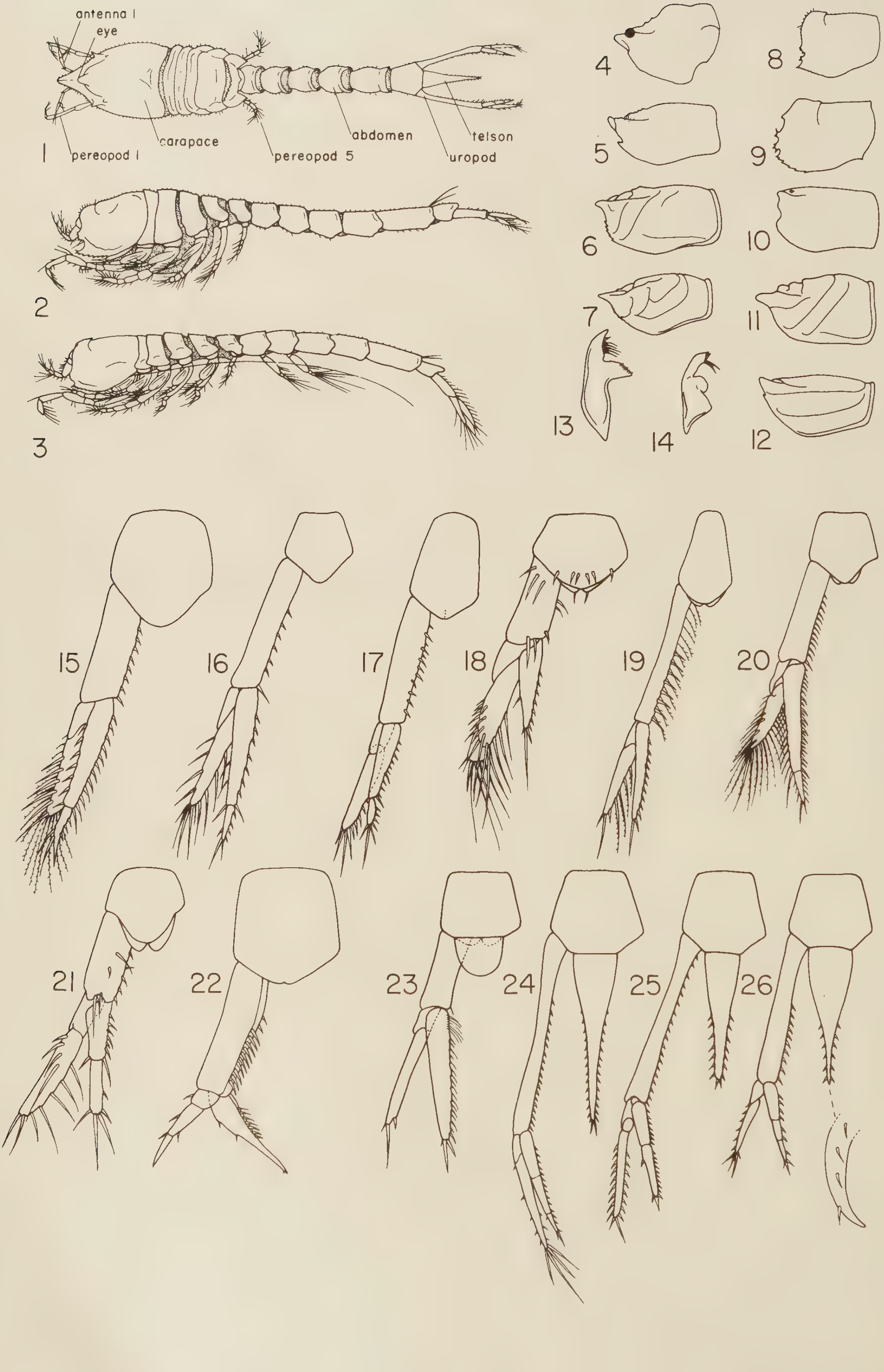

antenna I
eye
carapace
abdomen
telson
pereopod I
pereopod 5
uropod

Plate 13

CUMACEA

Figures mainly from Sars (1900) and Calman (1912), redrawn by Ruth L. von Arx.

Fig. 1. *Diastylis quadrispinosa*, female, dorsal view.

2. *Eudorella emarginata*, female, lateral view.

3. *Eudorella emarginata*, male, lateral view.

4-12. Carapace in lateral view of the following species:

4. *Almyracuma proximoculi*, male.

5. *Cyclaspis varians*, female.

6. *Diastylis polita*, male.

7. *Diastylis sculpta*, male.

8. *Eudorella hispida*, female.

9. *Eudorella truncatula*, female.

10. *Leptocuma minor*, male.

11. *Oxyurostylis smithi*, male.

12. *Petalosarsia declivis*, male.

13. *Petalosarsia declivis*, mandible.

14. *Eudorellopsis deformis*, mandible.

15-26. Dorsal view of last abdominal somite, uropod, and telson of the following species:

15. *Eudorella hispida*, female.

16. *Eudorella truncatula*, female.

17. *Leptocuma minor*, female.

18. *Eudorellopsis deformis*, female.

19. *Cyclaspis varians*, male.

20. *Eudorella emarginata*, female.

21. *Leucon americanus*, male.

22. *Almyracuma proximoculi*, male.

23. *Petalosarsia declivis*, female

24. *Diastylis quadrispinosa*, female.

25. *Diastylis sculpta*, female.

26. *Oxyurostylis smithi*, female; (inset: telson tip in side view).

7. Mandibles broadly truncate at base (fig. 14); male with 2 pairs of pleopods . . . . Family Leuconidae 8

7. Mandibles narrow or acuminate at base (fig. 13); male with 0, 3, or 5 pairs of pleopods 12

8. Pseudorostrum well developed . . . . *Leucon americanus*

8. Carapace truncate anteriorly without pseudorostrum 9

9. Uropods with outer ramus longer than inner ramus (fig. 18) . . . . *Eudorellopsis deformis*

9. Uropods with outer ramus shorter than inner ramus (figs. 15, 16) . . . . *Eudorella* 10

10. Body setose; approximately 14-18 teeth on carapace ventral margin (figs. 8, 15) . . . . *Eudorella hispida*

10. Body not setose; less than 14 teeth on carapace ventral margin 11

11. Anterior margin of carapace deeply emarginate in female, slightly emarginate in male (figs. 2, 3, 20) . . . . *Eudorella emarginata*

11. Anterior margin of carapace slightly emarginate in female, serrate or entire in male (figs. 9, 16) . . . . *Eudorella truncatula*

12. Endopod of uropod 2-jointed; 3 pairs of pleopods in male (figs. 10, 17) . . . . *Leptocuma minor*

12. Endopod of uropod 1-jointed; 0 or 5 pairs of pleopods in male (figs. 19, 22) 13

13. Male has no pleopods and a rudimentary second antenna; in female, uropod peduncle length about equal to maximum width of last abdominal somite (figs. 4, 22) . . . . *Almyracuma proximoculi*

13. Male has 5 pleopods and well developed second antenna; in female, uropod peduncle length greater than 2 times maximum width of last abdominal somite (figs. 5, 19) . . . . *Cyclaspis varians*

ANNOTATED LIST OF CUMACEANS

Almyracuma proximoculi Jones, 1959. Brackish water species, known only from Pocasset River. Adult size 3-4 mm.

**Campylaspis affinis* G. O. Sars, 1869. Not yet reported from Cape Cod waters, but expected to occur in deeper portions of this area.

**Campylaspis rubicunda* (Lilljeborg, 1855). Not yet reported from Cape Cod waters, but expected to occur in the deeper portions of this area.

Cyclaspis varians Calman, 1912. Brackish water species found in surface waters of Woods Hole Harbor and Vineyard Sound. Adult size 3-4 mm.

**Diastylis abbreviata* G. O. Sars, 1871. Not yet reported from Cape Cod waters, but expected to occur in deeper portions of this area.

Diastylis polita S. I. Smith, 1879. Found at depths less than ca. 35 meters from Nova Scotia to Block Island Sound. Adult size 12-14 mm.

Diastylis quadrispinosa G. O. Sars, 1871. Occurs from the Gulf of St. Lawrence to New Jersey in depths of 4-400 meters. Adult size 11 mm.

Diastylis sculpta G. O. Sars, 1871. In American waters occurs from Gulf of St. Lawrence to Long Island; low water to ca. 400 meters. Adult size 9-10 mm.

Eudorella emarginata (Kröyer, 1846). In American waters occurs from the Arctic to Martha's Vineyard in depths from 2-130 meters. Adult size 10-12 mm.

Eudorella hispida G. O. Sars, 1871. Occurs from the Arctic to Martha's Vineyard, in depths from 30-130 meters. Adult size 5-6 mm.

Eudorella truncatula (Bate, 1856). On U. S. coast reported from Massachusetts Bay to Block Island Sound, in depths of 30-100 meters. Adult size 4-5 mm.

PART 2. ORDER CUMACEA

By Roland L. Wigley

Cumaceans, although widespread in marine situations and with some species in brackish waters, are not well known to the average zoologist because of their small size and habit of living buried in sand or mud. The general body form is distinctive, characterized by an inflated cephalothorax and a slender, cylindrical abdomen. The carapace is moderately large, covering the anterior half of the cephalothorax. The integument in many species is rather heavily calcified and brittle. The first thoracic limb (maxilliped) bears a membranous epipodite, usually furnished with respiratory lamellae. A pseudorostrum is present in many species, formed by carapace lateral plates coming together above and in front of the head. Eyes are present in some species, sessile and usually coalesced to form a single organ on a lobe located mid-dorsally on anterior portion of carapace. First antenna with inner flagellum usually reduced or absent; second antenna vestigial in females, well developed in males. First 3 thoracic appendages modified as maxillipeds; remaining 5 as peraeopods. One pair of large styliform uropods present. Telson is distinct, or coalesced with last abdominal somite. Adults in this region generally range from 3 to 15 mm in length.

There is pronounced sexual dimorphism; pleopods are absent in all females and in males of some species, but males generally have from 1 to 5 pairs. Eggs are incubated in a marsupium, and hatch as postlarvae in which the past pair of peraeopods is undeveloped.

Cumaceans are primarily marine, but a few species occur in brackish waters. They are widely distributed in all oceans from intertidal zone to great depths in mid-ocean, most common subtidally. Basically benthic in habit, they commonly burrow in mud or sand. They occasionally undertake pelagic excursions, chiefly at night, at which time males greatly outnumber females.

KEY TO CUMACEANS OF THE CAPE COD REGION
(Figure references are to Plate 13)

1. Independent telson present (figs. 23-26) 2
1. Without independent telson (figs. 15-22) 7

2. Uropod inner ramus 1-jointed; telson without spines (figs. 13, 23) . . . . *Petalosarsia declivis*
2. Uropod inner ramus 2- or 3-jointed; telson with lateral and apical spines (figs. 24-26) 3

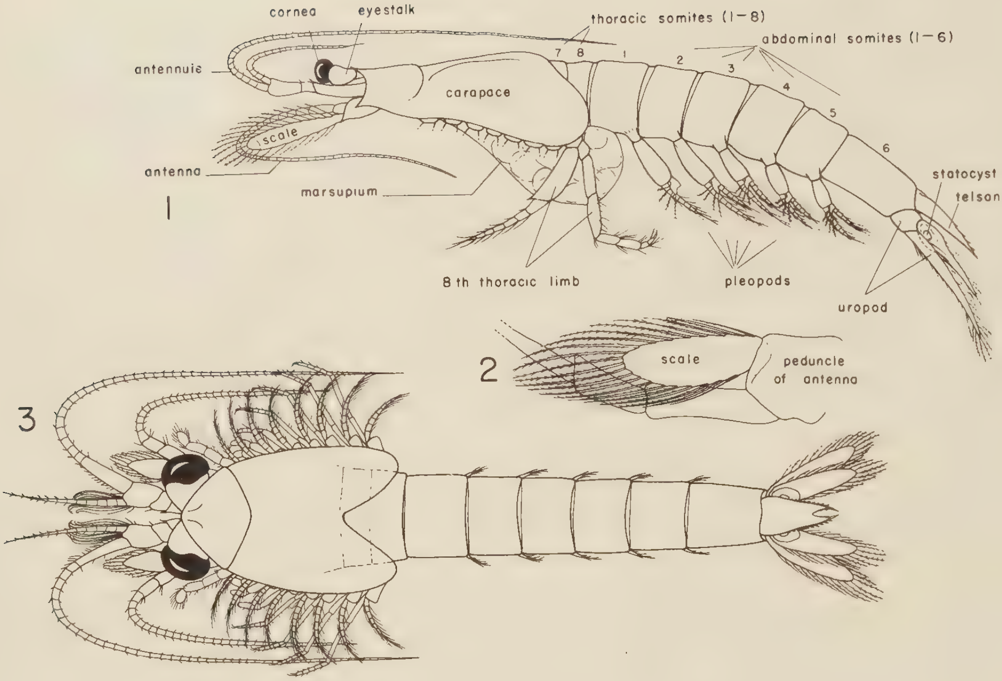
3. Telson with 5 apical spines; male without pleopods . . . *Lamprops quadriplicata*
3. Telson with 0 or 2 apical spines; male with 2 pairs of pleopods . . . . Family Diastylidae 4

4. Telson apex upturned, without apical spines (figs. 11, 26) . . . . *Oxyurostylis smithi*
4. Telson apex not upturned, 2 apical spines (figs. 24, 25) . . . . *Diastylis* 5

5. Carapace with 4 large spines on dorsal surface (figs. 1, 24) . . . . *Diastylis quadrispinosa*
5. Carapace without dorsal spines (figs. 6, 7) 6

6. Carapace with 3 oblique lateral ridges; horizontal ridge on postero-lateral section of carapace in male (fig. 6) . . . . . *Diastylis polita*
6. Carapace with 4 oblique lateral ridges; without horizontal ridge on postero-lateral section of carapace in male (figs. 7, 25) . . . . *Diastylis sculpta*

Plate 12



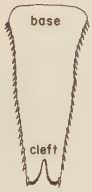
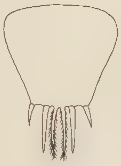
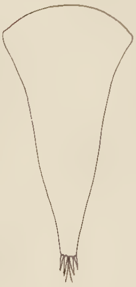
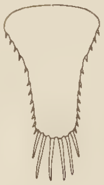
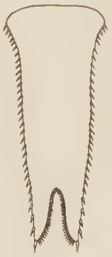
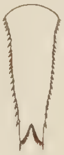
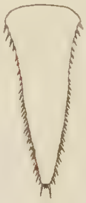
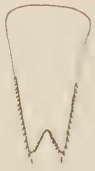
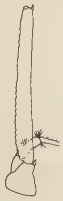
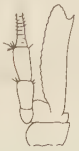
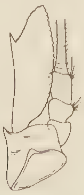
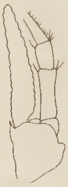
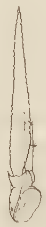
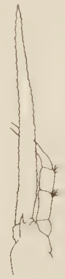
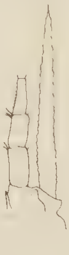
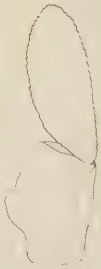
4	5	6	7	8	9	10	11
Praunus flexuosus	Erythrops erythrophthalma	Meterythrops robusta	Mysidopsis bigelowi	Mysis mixta	Mysis stenolepis	Neomysis americana	Heteromysis formosa
							
							

Plate 12

MYSIDACEA

Figures mainly from Tattersall (1951) and
Tattersall and Tattersall (1951), redrawn
by Ruth L. von Arx.

Fig. 1. Side view of a typical mysid, ovigerous female, thoracic legs 1-7 omitted.

2. Antennal scale and basal portion of antenna of a typical mysid.

3. *Heteromysis formosa*, dorsal view.

4-11. Upper row shows telsons, lower row shows antennal scales, both in dorsal view, of the following species:

4. *Praunus flexuosus*.

5. *Erythrops erythrophathalma*.

6. *Meterythrops robusta*.

7. *Mysidopsis bigelowi*.

8. *Mysis mixta*.

9. *Mysis stenolepis*.

10. *Neomysis americana*.

11. *Heteromysis formosa*.

on the carapace and clear bright yellow pigment spots on the ventral body surface. Adult length 9-11 mm.

Heteromysis formosa S. I. Smith, 1873. A common species from New Jersey to Canada. Frequently in small swarms inside dead bivalve shells such as Spisula. Intertidal to 248 meters. Males semi-translucent, but parts of the females are a rose color. Adult length 6-9 mm.

Meterythrops robusta S. I. Smith, 1879. Uncommon; in the western Atlantic, occurs from Cape Cod to Greenland. 66-300 meters. Adult length 14-16 mm.

Mysidopsis bigelowi Tattersall, 1926. A warm water species, from Louisiana to Cape Cod. Most common at shallow shelf depths, 16-50 meters, but has been found to 196 meters. Adult length 7.5 mm or somewhat more.

Mysis mixta Lilljeborg, 1852. Occasionally referred to as Michtheimysis mixta. A common species of the east coast from Woods Hole to Canada. Closely related to Mysis stenolepis; however, in contrast, M. mixta inhabits areas where algae and Zostera are absent. Intertidal to 200 meters. Adult length 20-25 mm.

Mysis stenolepis S. I. Smith, 1873. Sometimes referred to as Michtheimysis stenolepis and Mysis spinulosus. Inhabits intertidal and shallow shelf waters from New Jersey to Gulf of St. Lawrence. Closely related to M. mixta (see above), but is a more strictly littoral weed inhabiting species. Adult length 25-30 mm.

Neomysis americana (S. I. Smith, 1873). Mysis americana is a synonym. Very common, from Virginia to the Gulf of St. Lawrence. Intertidal to 214 meters. Adult length 10-12 mm.

Praunus flexuosus (Müller, 1776). A European species of relatively large size, first found in American waters in 1960. Has been reported only in the harbor at Barnstable, Mass. In Europe is one of the commonest species in brackish waters and tidal zones along the coast. Adult length 24-25 mm.

REFERENCES ON MYSIDS

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Mysids inhabit a wide variety of benthic and planktonic habitats. They are com-
n in brackish and marine waters, but no freshwater forms are known in this region.
sids are an important link in littoral and continental shelf food webs, and are par-
cularly valuable as food for small species of fish as well as the young of larger
shes. Seasonal inshore-offshore migrations and other horizontal movements have been
served for a few species. Pronounced vertical migrations in which they swim upward
ring hours of darkness are characteristic of this group.

KEY TO MYSIDACEA OF THE CAPE COD REGION
(Figure references are to Plate 12)

Telson with posterior end cleft (figs. 4, 8, 9, 11) 2
Telson with posterior end entire (figs. 5-7, 10) 5

Antennal scale with setae present on both inner and outer margins (fig. 2) 3
Antennal scale with outer margin devoid of setae and terminating in an articulated spine (fig. 4) . . . . *Praunus flexuosus*

Telson with the entire lateral margins armed with spines. Antennal scale elongate, width 9 to 12 times length, produced into an acute apex (figs. 8, 9) 4
Telson with basal one-half of the lateral margins devoid of spines; antennal scale elliptical, apex blunt, 3.5 times as long as broad (figs. 3, 11) . . . . *Heteromysis formosa*

Antennal scale approximately 9 times as long as broad, outer margin nearly straight, telson lateral margin spines more than 30, extending posteriorly to apex (fig. 8) . . . . *Mysis mixta*
Antennal scale approximately 12 times as long as broad, outer margin concave in outline; telson lateral margin spines 25, extending posteriorly as far as the cleft (fig. 9) . . . . *Mysis stenolepis*

Antennal scale with setae present on both inner and outer margins; telson lateral margins armed with numerous spines (figs. 7, 10) 6
Antennal scale with setae absent on outer margin, terminating in a strong spine; telson without spines on lateral margins (figs. 5, 6) 7

Antennal scale about 10 times as long as broad (fig. 10); telson subequal in length to endopod of the uropod . . . . *Neomysis americana*
Antennal scale about 5 times as long as broad (fig. 7); endopod of the uropod 1.5 times as long as the telson . . . . *Mysidopsis bigelowi*

Eyes dorso-ventrally flattened, cornea kidney-shaped, red color; telson length subequal to its greatest width (fig. 5) . . . . *Erythrops erythrophthalma*
Eyes globular not dorso-ventrally flattened, cornea black; telson elongate, length 2 times its greatest width (fig. 6) . . . . *Meterythrops robusta*

ANNOTATED LIST OF MYSIDS

hrops erythrophthalma (Göes, 1863). Occasionally referred to as *Erythrops goesii*. Inhabits deeper waters, 40-275 meters, from Cape Cod to the Arctic. One of the most beautifully colored New England mysids. Eyes brilliant carmine red; opaque white pigment spots scattered over the body; an orange-red dorsal patch

PART I. ORDER MYSIDACEA

By Roland L. Wigley

The mysids are the most typically shrimp-like ("caridoid") of the various peracaridan orders. They are adapted for swimming, with elongated bodies and a well developed carapace covering almost the entire thorax. The lightly calcified integument is thin and flexible. The antennules are biramous, having multi-segmented flagella; antennae have an exopod, usually in the form of a flattened scale (antennal scale); the endopod is flagelliform, composed of numerous segments. Eyestalks are cylindrical, well developed, terminating in a prominent brown or black (rarely red) cornea. The eight thoracic segments each bear biramous appendages; branchiae are absent in the species listed here. Females bear a large marsupium (hence the common name Opossum Shrimp) composed of 2-7 pairs of oöstegites attached to the thoracic limbs. The pleopod structure varies, depending on sex and species.

Chapter XII. Phylum ARTHROPODA, Peracaridan Crustaceans.

Part 1. Mysidacea
Part 2. Cumacea

by Roland L. Wigley

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Keys to Marine Invertebrates of the Woods Hole Region

RALPH I. SMITH · EDITOR

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SOME QUANTITATIVE COMPARISONS OF OFFSHORE MEIOBENTHOS AND MACROBENTHOS SOUTH OF MARTHA'S VINEYARD

BY ROLAND L. WIGLEY AND A. D. MCINTYRE

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SOME QUANTITATIVE COMPARISONS OF OFFSHORE MEIOBENTHOS AND MACROBENTHOS SOUTH OF MARTHA'S VINEYARD

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Bureau of Commercial Fisheries, Woods Hole, Massachusetts

and

A. D. McIntyre
Marine Laboratory, Aberdeen, Scotland

ABSTRACT

Quantitative samples were taken from the offshore area south of Martha's Vineyard, Massachusetts, in June 1962, to compare the macrobenthos with the meiobenthos. Macrobenthos infauna ranged from 700 to 5,500 individuals per m^2 and (excluding individuals larger than 5 g) from 21 to 82 g/m^2. The principal taxonomic groups were Crustacea, Mollusca, Echinodermata, and Polychaeta. Meiobenthos ranged from 117,000 to 988,000/m^2 in number of individuals and from 0.6 to 4.6 g/m^2 in weight. Major taxonomic groups were Nematoda, by far the most numerous component, Polychaeta, Kinorhyncha, and Foraminifera. Meiobenthos populations in offshore areas are shown to be at least as rich as those previously known from shallow coastal waters. Numbers and weight of both macrobenthos and meiobenthos were lowest in deep water and highest at shallow or mid-depths. Meiobenthos was most plentiful on sandy sediments, and, although this applied to numbers of macrobenthos, the weight of the latter was generally highest on fine or moderately fine sediments. The ratio of macro- to meiobenthos over all samples was numerically 1:70 and by weight 24 : 1. These ratios were remarkably consistent from station to station in spite of variations in faunal components and the environment.

INTRODUCTION

Quantitative comparisons of subtidal nthic meiofauna with macrofauna have en made in only five investigations. ogh and Spärck (1936) studied material m the vicinity of Copenhagen, Denmark; are's (1942) material was from the En-sh Channel off Plymouth; Sanders (1958) d Wieser (1960) studied the fauna of zzards Bay, Massachusetts; and Mc-yre (1961) investigated two areas off tland.

series of samples collected in June 2 from the research vessel *Delaware* de it possible to compare relative quan-es of meiobenthos and macrobenthos in ious substrata and at different depths southern New England. There appear be no reports in the literature giving antitative data on either macrobenthos meiobenthos populations for this area. hough our observations are limited to tively few samples, they extend the ge of our knowledge considerably and the first measurements of this kind from offshore waters in the western Atlantic Ocean.

We wish to thank Roger B. Theroux and Timothy W. Robbins for assistance at sea and in the laboratory.

MATERIALS AND METHODS

Data presented here are based on samples from *Delaware* Cruise 62-7, representing 10 stations (46–55) spaced approximately at 10-mile (18-km) intervals along longitude 71°00′ W south of Martha's Vineyard. Station positions, depths, and bottom temperatures are listed in Table 1 and illustrated in Fig. 1. Water temperatures were measured with a bathythermograph attached to the grab, except at Stations 54 and 55. At these two deepwater stations, sediment temperature was measured, using a standard bulb thermometer. Water depths ranged from 40 m near shore to 567 m on the continental slope.

Bottom water temperatures ranged from 5.0C (41F) in deep water to 10.8C (51.5F) near the periphery of the continental shelf.

TABLE 1. *Station location and physical features. All stations located on longitude 71°00′ W*

Station	Depth (m)	Bottom water temperature (C)			N lat
		June 1962	Approximate annual range*		
			Minimum	Maximum	
46	40	9.7	3	14	41°10′
47	51	6.4	3	14	41°00′
48	58	6.1	4	14	40°50′
49	69	6.3	4	12	40°40′
50	84	6.3	6	11	40°30′
51	99	9.4	8	11	40°21′
52	146	10.8	10	12	40°10′
53	179	10.8	11	11	40°06′
54	366	6.6†	5‡	7‡	39°59′
55	567	5.0†	4‡	5‡	39°56′

* Based on data from Bigelow (1933).
† Bottom sediment temperature.
‡ Based on data from Townsend (1901).

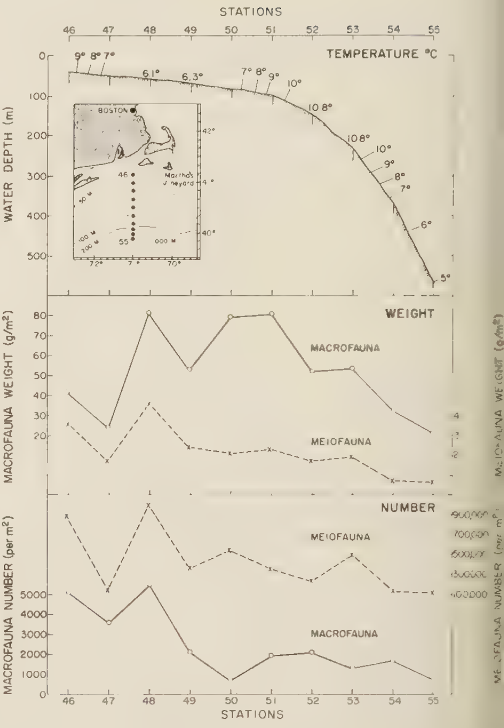

FIG. 1. Water depth-temperature profile together with graphs of macrofauna and meiofauna weights and numbers, plus station location chart.

In addition to the June temperatures, the temperature extremes during a 1-year period are pertinent and are included in Table 1, but only approximate values are available. They ranged from 3 to 14C at shallow-water stations, 10 to 12C near the continental shelf edge, and 4 to 7C at deepwater stations. The temperature regime of bottom waters south of Martha's Vineyard is complicated by a moderately cold water mass midway out on the shelf and a warm water mass near the shelf edge. Occasional shifts in location of these masses result in wide temperature fluctuations at any given location over a time span of several years or more. Minimum annual bottom water temperatures on the shelf generally occur in February–March, and maximum temperatures occur in September–November; June temperatures are intermediate between the two extremes (Townsend 1901; Bigelow 1933; data in the hydrographic files at the Woods Hole Oceanographic Institution).

Bottom sediments varied from predominantly gravels and sands inshore to silt clays at offshore stations. Particle size analysis of the deposit for each station is listed in Table 2.

At each station, two hauls were made with a 0.1 m² Smith-McIntyre grab, and the materials for macrobenthos studies were washed through a 1-mm screen. From one grab haul at each station, a meiobenthos core was collected in the following way. The grab was carefully kept in an upright position until the water had drained off; then a top plate on the grab was removed, exposing the surface of the deposit. After ensuring that this surface was even and undisturbed, a core sample was taken using a plastic tube of 34.8 mm inside diameter, giving a surface area of 9.50 cm². The top 4 cm of the core was then pushed out from below with a plunger, and preserved in 5% formalin. A possible source of error in this method of collecting meiobenthos is that a downrush of water when the grab strikes bottom might disturb the surface layer before the grab bites. This was not considered a serious objection, since the type of grab used has bucket tops made of fine-mesh screen instead of solid plates, which is thought to reduce the wash considerably.

TABLE 2. *Sediment grain size composition, expressed as percentage weight*

ation	Grain size classes (mm) > 2.00	2.000–1.000	1.000–0.500	0.500–0.250	0.250–0.125	0.125–0.062	< 0.062	Mean grain size (mm)	Sorting coeffi-cient*
46	0.10	0.40	34.20	55.72	9.26	0.32	0	0.58	0.50
47	12.12	49.27	25.06	11.47	1.63	0.14	0.31	1.47	0.90
48	0	0.59	4.57	31.91	46.17	2.31	14.45	0.25	0.80
49	0.65	2.06	5.02	14.57	17.90	9.27	50.53	0.12	1.92
50	0	0	1.24	1.42	1.55	6.25	89.54	0.04	0.87
51	1.31	0.70	10.98	19.22	10.46	3.31	54.02	0.13	2.38
52	7.30	2.89	8.58	37.89	13.05	2.16	28.13	0.14	2.56
53	0.58	2.14	4.78	48.45	16.42	2.14	25.49	0.13	1.98
54	0	0	1.16	3.34	18.52	9.43	67.55	0.08	1.47
55	1.55	1.91	5.57	20.24	26.69	16.68	27.36	0.16	1.65

* Phi deviation measure.

In the laboratory, the macrobenthos col- ctions were sorted and the animals iden- ied, counted, and weighed in the usual ay. External moisture was removed from e specimens by means of blotting paper. ollusk shells and Foraminifera tests of ing specimens are included in the eights. The procedure for processing eiobenthos samples was as follows. The re was first washed through a 1-mm reen and all animals retained were re- rded and returned to the appropriate acrobenthos sample. The filtrate was rther washed through a 74-μ screen, and residue on this screen was placed over- ght in an aqueous solution of rose bengal staining. It was later examined in 70% ohol, and all stained animals were ked out by direct search under a binocu- microscope. The filtrate of the 74-μ een was not examined, since it was own from unpublished studies of North material that this fraction was likely contain insignificant faunal weights. t weights of nematodes were calculated m measurements of length and width, uming a specific gravity of 1.13 (*see* eser 1960). Approximations for other ups were obtained from weighings of ge numbers of individuals.

RESULTS

Macrobenthos

ll living organisms retained by the m mesh sieving screen were considered robenthos forms. Components of this group ranged from small organisms, such as nematodes and Forminifera that weighed less than 0.001 g each, to large lamellibranchs that individually weighed more than 100 g. Numbers of individuals and wet weights of the macrobenthos at each station are listed in Table 3. The values given are means for a pair of samples from each station. For purposes of comparison with previous studies, the macrobenthos data have been separated into two major categories, 1) infauna and 2) epifauna. The infauna has been subdivided into two size groups: Group A—specimens weighing less than 5 g each; Group B—specimens weighing more than 5 g each.

Three major macrofaunal groups are evident from this sampling, and their distribution corresponds to biotopic and geographic features. Beginning inshore and progressing seaward, the groups are as follows: 1) an inner continental shelf group characterized by amphipods and polychaetes, 2) an outer continental shelf group characterized by echinoderms and mollusks, and 3) a continental slope group characterized by a general paucity of fauna but dominated by polychaetes and including small numbers of certain miscellaneous groups.

Macrofauna in the inner continental shelf group occurred at Stations 46–48. Depths at these stations ranged from 40 to 58 m; bottom temperatures ranged from 6.1 to 9.7C; and the sediments were principally sands or fine gravels. Burrowing amphi-

TABLE 3. *Macrobenthos wet weight (g/m²) and number of individuals (per m²) at each station*

	Stations									
	46	47	48	49	50	51	52	53	54	55
Infauna										
Group A (Individuals weighing less than 5 g each)										
Crustacea										
Number	4,235	2,990	3,465	790	20	55	5	25	20	5
Weight	22.26	12.35	33.07	3.60	0.05	1.50	0.02	0.08	0.10	0.02
Mollusca										
Number	45	0	155	165	210	525	320	260	90	25
Weight	1.45	0	1.18	10.98	2.98	9.33	13.32	6.35	0.88	2.15
Echinodermata										
Number	15	0	15	15	105	740	455	210	30	10
Weight	0.05	0	0.08	0.02	25.85	33.15	8.05	36.90	2.02	10.02
Polychaeta										
Number	600	440	1,735	1,105	325	270	955	325	795	425
Weight	11.15	10.05	46.62	37.98	47.55	6.37	24.70	8.08	12.90	7.95
Miscellaneous										
Number	245	155	125	70	40	330	350	460	760	265
Weight	6.70	1.90	0.60	0.55	2.27	30.57	5.37	1.91	16.08	0.95
TOTAL										
Number	5,140	3,585	5,495	2,145	700	1,920	2,085	1,280	1,695	730
Weight	41.61	24.30	81.55	53.13	78.70	80.92	51.46	53.32	31.98	21.09
Group B (Individuals weighing more than 5 g each)										
Number	—	—	15	—	15	5	—	5	—	—
Weight	—	—	1,274.10	—	155.55	46.75	—	23.45	—	—
Epifauna										
Number	—	—	5	—	25	5	55	5	—	—
Weight	—	—	0.03	—	32.45	0.02	7.20	0.10	—	—
GRAND TOTAL										
Number	5,140	3,585	5,515	2,145	740	1,930	2,140	1,290	1,695	730
Weight	41.61	24.30	1,355.68	53.13	266.70	127.69	58.66	76.87	31.98	21.09

pods were particularly abundant, averaging 3,000 to 4,000/m² in number and from 10 to 30 g/m² in weight. Some arenaceous Foraminifera and polychaetes in the families Scalibregmidae and Sabellidae were less abundant, but they occurred only at these stations.

Faunal composition at Station 49 appears to be transitional between the inner and outer continental shelf groups. Amphipods at this station constituted a significant number, but they were much less abundant than that expected in a typical inner shelf association. The occurrence of large quantities of mollusks is characteristic of the outer shelf group. Polychaetes, particularly the scoleciform types, were dominant in both weight and number.

Outer continental shelf fauna occurred at Stations 50 through 53, where the depths ranged from 84 to 179 m and bottom temperatures ranged from 6.3 to 10.8C. Sediments were of two types: at Stations 50 and 51, silt clay predominated, while at Stations 52 and 53, medium sand predominated. Mollusks were relatively numerous on this portion of the shelf, ranging in number from 200 to 500/m²; lamellibranchs were the principal group. Echinoderms, consisting mostly of brittle stars plus a few holothurians, averaged 100 to 700/m² and were a characteristic component of the outer shelf macrofauna.

Continental slope fauna was represented at Stations 54 and 55. These are the two deepest stations, 366 and 567 m, respectively. Bottom temperatures ranged from 5.0 to 6.6C, with very little seasonal variation, and the sediments were composed primarily of silt clay and fine sand. Macrofauna composition at these localities was not particularly characteristic, except for the occurrence of tanaids, harpacticoid copepods, and pogonophores. Polychaetes, ABLE 4. *Meiobenthos wet weight (mg/10 cm²) and number of individuals (per 10 cm²) at each station*

Faunal group	Stations									
	46	47	48	49	50	51	52	53	54	55
umber/10 cm²										
Nematoda	685	50	924	328	507	302	202	438	117	110
Kinorhyncha	19	2	15	–	2	–	–	–	–	–
Foraminifera	4	4	14	20	7	40	25	32	6	4
Copepoda	122	45	15	2	–	–	4	15	–	1
Ostracoda	2	1	7	–	–	1	1	1	–	–
Gastrotricha	7	5	–	–	–	–	–	–	–	–
Halicaridae	–	1	1	1	–	–	–	–	–	–
Nauplii	1	9	2	–	–	–	–	–	–	–
Polychaeta	30	10	10	6	19	5	3	4	4	1
Amphipoda	3	–	–	4	–	–	–	–	–	–
Isopoda	–	–	–	–	–	–	–	2	–	–
Cumacea	1	–	–	–	–	1	–	–	–	–
Lamellibranchia	1	–	–	–	1	2	–	–	–	1
Echinodermata	–	–	–	1	1	–	–	–	–	–
Total	875	127	988	362	537	351	235	492	127	117
Per cent Nematoda	78	39	94	91	94	86	86	89	92	94
eight mg/10 cm² (values are equivalent to g/m²)										
Nematoda	1.016	0.155	2.052	1.066	0.923	0.570	0.349	1.004	0.243	0.359
Kinorhyncha	0.947	0.010	0.074	–	0.032	–	–	–	–	–
Foraminifera	0.046	0.038	0.163	0.242	0.063	0.526	0.244	0.389	0.053	0.038
olychaeta	0.958	1.410	2.000	0.810	0.989	1.105	1.116	0.442	0.453	0.105
ll other groups	0.632	0.074	0.268	0.289	0.105	0.132	0.037	0.060	—	0.105
Total	3.599	1.687	4.557	2.407	2.112	2.333	1.746	1.895	0.749	0.607

) to 800/m², were the most abundant pup, and the nereidiform and spioniform es were particularly common. Forami- era were also quite abundant (200 to /m²), but because of their small size ir weight contribution was small (aver- 1.3 g/m²). Pogonophora are generally e throughout the world, so it was inter- ing to find representatives of this group all samples from the continental slope. eir average density was 28/m².

lthough there was considerable varia- n in weight and number from one station nother, quantitative relationships of the rofauna with both water depth and iment type can be detected. Numbers individuals were highest, up to about 0/m², in shallow water and in coarser osits, dropping to about one-fifth of value in deeper water and in finer de- its. Weight values showed a slightly erent trend, being highest at interme- e depths and in the finer sediments.

Meiobenthos

ll animals passing through a 1-mm mesh but retained on a 74-μ mesh are here regarded as meiobenthos. Numbers and weights of these animals from each station (Table 4) indicate that there are three meiobenthos zones or groupings, geographically similar to those described for macrobenthos.

The inner shelf group is characterized by a varied and abundant meiobenthos, 11 major taxonomic groups being represented. The number of individuals averaged 662/10 cm², with a corresponding wet weight of 3.28 mg.

In the outer shelf group, including Station 49, the fauna is both less varied and, except for calcareous Foraminifera, less numerous, with an average number of 399 individuals/10 cm² and a weight of 2.10 mg. Within this group, the largest population occurred at Station 50, which had the highest silt clay content in the deposit.

At the slope stations, the fauna was relatively sparse, with nematodes present in only small numbers and the other groups much reduced or absent. The average numbers and weights per 10 cm^2 were 122 and 0.68 mg, respectively.

Gastrotrichs, kinorhynchs, and, to a lesser extent, copepods and ostracods tended to be confined to shallower water, while Foraminifera were most abundant at intermediate depths. Nematoda comprised the major group, being present in all samples, and they were by far the most numerous animals. They were least abundant on a substratum of gravel, where they made up only 39% of the fauna, but at all other stations they composed between 78% and 94%, numerically, of the total fauna.

A few of the animals listed in Table 4 are juveniles whose adults would have been retained on the 1-mm screen. These include the lamellibranchs and echinoderms, as well as some of the polychaetes and crustaceans (except copepods). The greater part, however, is made up of animal groups most of whose species would pass through a 1-mm screen (or even through a 0.5-mm screen) at any stage of their life history.

Since the 74-μ screen was the smallest used, any animals passing through this were lost. Unpublished work regarding the North Sea suggests that material lost in this way would consist largely of nematodes (mainly immature stages) and that, while their numbers may be significant, the weights would be small. Another source of error is that only the top 4 cm was examined. This fraction of the core contains the greater part of the fauna, but small numbers of animals, mainly nematodes, must have been lost. For these reasons, the values given in Table 4 must be regarded as minimum estimates.

DISCUSSION

Benthic fauna in the area studied was quantitatively moderate to rich, compared with nearby inshore areas and north European localities. Although considerable variation was evident, both macro- and meiobenthos exhibited similar station-to-station abundance trends. Numbers of individuals in the fauna in both categories were highest in coarse-grained sediments in shallow water and considerably lower in fine-grained sediments in deep water. Also biomass in both categories was moderately high in shallow water, highest at intermediate depths, and lowest in deep water.

Results from two stations, 47 and 48 were strikingly different from all the rest. The first carried a comparatively sparse fauna, the other was unusually rich. At Station 47, where sediments consisted chiefly of fine gravels and coarse to medium sands we found moderately low quantities of both macro- and meiobenthos, with numbers of individuals averaging 3,600 and 127,000/m^2, respectively, and corresponding weights of 24 and 1.7 g/m^2. Nematodes in particular were sparse in the meiobenthos, although they were relatively numerous in the macrobenthos. Not a single mollusk or echinoderm was present. Unsuitable substratum combined with unfavorable biological or hydrographic conditions may account for this limited taxonomic representation and rather low faunal density. Conversely, in medium and fine sand sediments of adjacent samples, Station 48, there was an exceptionally abundant benthic fauna. Average number and weight of the small (Group A) macrobenthic infauna were 5,500/m^2 and 82 g/m^2. In addition to this were its large infaunal organisms composed exclusively of the bivalve mollusk *Arctica islandica* Linnaeus; they averaged 1,274 g/m^2. Thus, the total of all macrobenthos as this locality amounted to 1,356 g/m^2. A pertinent factor that may in part account for this unusually rich benthic fauna is the abundant zooplankton in the overlying waters (Bigelow and Sears 1939).

Table 5 gives summary data for comparing quantities of macro- and meiofauna at the 10 stations south of Martha's Vineyard. Weights of the former ranged from 21 to 82 g/m^2, and of the latter from 0.6 to 4.6 g/m^2. All stations considered, the macrobenthos weight was 24 times that of meiobenthos, the ratio ranging from 12 : 1 to 43 : 1 (Fig. 2). There is no obvious connection between this ratio and the sediment type, but the general trend was for the ratio to increase with water depth due to the fact that meiobenthos weights de-

TABLE 5. *Density of macro- and meiobenthos expressed as numbers of individuals and weights per m²*

	Number of individuals			Weight		
tion	Macro-benthos*	Meio-benthos	Ratio	Macro-benthos*	Meio-benthos	Ratio
6	5,140	875,000	1:170	41.61	3.60	12:1
7	3,585	127,000	1: 35	24.30	1.69	14:1
8	5,495	988,000	1:180	81.55	4.56	18:1
9	2,145	362,000	1:170	53.13	2.41	22:1
0	700	537,000	1:770	78.70	2.11	37:1
1	1,920	351,000	1:185	80.92	2.33	35:1
2	2,085	235,000	1:110	51.46	1.75	29:1
3	1,280	492,000	1:380	53.32	1.90	28:1
4	1,695	127,000	1: 75	31.98	0.75	43:1
5	730	117,000	1:160	21.09	0.61	35:1
erage	2,477	421,100	1:170	51.81	2.17	24:1

Group A infauna. For explanation, *see* p. 487.

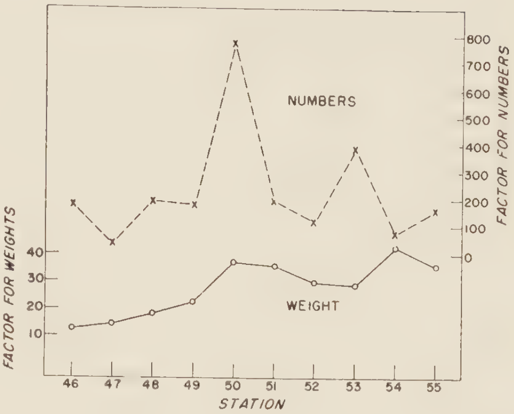

FIG. 2. Factors by which meiobenthos exceeds macrobenthos numbers (top graph) and macrobenthos exceeds meiobenthos weights (lower graph) at each station.

ased relatively more than the macro- hthos as the water deepened. Numbers individuals had a much wider range, ying in the macrobenthos from 700 to 00/m² and in the meiobenthos from ,000 to 988,000/m². Thus, the latter eeded the former by factors ranging m 35 to 770, and, considering all stations, factor averaged 170. The striking fea- e is the high degree of uniformity (Fig. At seven of the stations, the factor was arkably close to the average, and only Station 50 was there an extreme devia- . The high ratio here was due to low nbers of macrobenthos rather than to exceptionally high meiobenthos.

Since workers in different areas have employed various methods in processing macrobenthos and meiobenthos, particularly in regard to sieving screen mesh sizes, precise comparisons between our results and others are precluded. However, it is appropriate briefly to review two main aspects: 1) nematode density, and 2) relative quantities of macrobenthos versus meiobenthos, reported for other areas to provide a basis for generalized comparisons with our findings.

One common feature of all reports on subtidal meiobenthos is the high proportion

ABLE 6. *Numbers of nematodes per 10 cm² recorded by various workers, listed according to water depth and sediment type*

r depth (m)	Number of nematodes (per 10 cm²)	Sediment type	Location	Authority
18	798	Mud	Massachusetts	Wieser (1960)
–30	364	Sand	Massachusetts	Wieser (1960)
24	252	Mud	Scotland	Moore (1931)
30	474	Sand	Mediterranean Sea	Bougis (1950)
45	<90	Mud	English Channel	Mare (1942)
-110	86	Mud	Scotland	McIntyre (1961)
16	157	Mud	Scotland	Moore (1931)
40	62	Mud	Scotland	McIntyre (1961)
–58	805	Sand	Off southern New England	Present work
1	50	Sandy gravel	Off southern New England	Present work
–99	379	Silt clay	Off southern New England	Present work
–179	320	Medium sand	Off southern New England	Present work
–567	114	Fine sand, silt clay	Off southern New England	Present work

of nematodes in the samples. Data for this are given in Table 6. Certain workers have used screens of 100 μ or coarser (Moore 1931; Mare 1942; McIntyre 1961), so their figures are certainly underestimates, but Bougis (1950) corrected his data for loss of small nematodes, and Wieser (1960) gives total counts. The present work gives values for a greater variety of sediments and depths than were previously available, and, even though they must be regarded as minimum estimates, they do show that at moderate depths offshore, the populations are as numerous as in inshore areas; that in water depths of 100–200 m, high populations are still found; and that, even on the continental slope, significant numbers of nematodes occur—indeed, there were higher populations there than on sandy gravel sediments in shallow water.

Only a few previous investigations have been made that quantitatively compare the subtidal macrobenthos with the meiobenthos. Reliable data on this subject are available for four areas: 1) in the English Channel, the macrobenthos : meiobenthos ratio was ca. 90 : 1 for weights and ca. 1 : 60 for numbers of individuals (Mare 1942); 2) in Buzzards Bay, Massachusetts, the ratio was ca. 33 : 1 for weights (H. L. Sanders, personal communication), and the ratio for numbers of individuals ranged from ca. 1 : 30 to 1 : 140 (Wieser 1960); 3) on the Fladen ground in the central North Sea, the ratio was ca. 40 : 1 for weights and ca. 1 : 40 for numbers of individuals (McIntyre 1961); and 4) in Loch Nevis, western Scotland, the ratio was ca. 15 : 1 for weights and ca. 1 : 100 for numbers of individuals (McIntyre 1961). Despite the varied taxonomic composition of the fauna from one locality to another and the different processing methods used, the macrobenthos : meiobenthos ratios were unusually consistent from one area to another.

Macrobenthos : meiobenthos ratios for samples south of Martha's Vineyard agree well with ratios from the localities listed above. Ratios for numbers of individuals in the offshore Martha's Vineyard samples range from 1 : 35 to 1 : 770, compared with 1 : 30 to 1 : 140 for the other areas. Weight ratios for the offshore Martha's Vineyard samples range from 12 : 1 to 43 : 1, compared with 15 : 1 to 90 : 1 reported for other localities.

CONCLUSIONS

The benthic macrofauna and meiofauna on the continental shelf and upper continental slope south of Martha's Vineyard were moderate to rich, compared with other regions.

Numbers of individuals and weights comprising the macro- and meiobenthos were lowest in deep water and highest at shallow and mid-depths.

A major portion of the macrofauna was composed of four taxonomic groups. Crustacea were common only in inshore, shallow waters; Mollusca and Echinodermata were prevalent at moderate depths along the outer portion of the continental shelf. Polychaeta were rather abundant at all stations.

A small number of large (greater than 5 g) organisms radically increased the total biomass values at a few stations.

Meiofauna formed a moderate-to-small share of the benthic biomass.

Numerically, nematodes were the principal meiofauna component at all depths sampled, and they, together with polychaetes, kinorhynchs, and Foraminifera were the main meiofauna groups in terms of weight.

The relative quantity of macrobenthos compared to meiobenthos was quite similar from station to station in the offshore Martha's Vineyard region, and as a group these proportions agree rather closely with similar ratios based on samples from European and inshore New England waters Rather good consistency was evident in the macrobenthos : meiobenthos ratios between different areas and between samples within a given area, even though in many cases the taxonomic composition and biotopic features differed markedly.

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Phytoplankton Productivity at Beaufort, N. C.

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Regular measurements were made in the Beaufort channel for one year of standing crop of phytoplankton, respiration, photosynthesis and physical factors thought to influence primary production. Throughout the study, nanno plankton was dominant over net plankton. Photosynthesis had a pronounced seasonal cycle with higher values in summer; respiration was irregular but generally greater in warm weather. Average gross photosynthesis and respiration were estimated to be respectively 786 and 243 mg. C m.^{2} day for June through October, and 249 and 118 mg. C m.^{2} day for the remainder of the year in a water column equal to the average depth of the estuary, 1.5 m. Gross photosynthesis correlated neither with standing crop as estimated from pigment concentration nor with insolation entering the water, but had a highly significant correlation with water temperature. The relatively low plankton productivity was thought to arise from rapid tidal flushing of the estuary.

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OBSERVATIONS ON SPAWNING PACIFIC SARDINES[1]

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While the U.S. Bureau of Commercial Fisheries research vessel, *Black Douglas*, lay at anchor in South Bay, Cedros Island, Baja California, Mexico, scientific personnel aboard observed unfamiliar behavior by a school of Pacific sardines, *Sardinops caeruleus* (Girard). This observation took place on August 16, 1958, between dusk (approximately 1830 PST) and 2225 PST. Collection of almost 200 fish in "running ripe" condition, i.e. eggs and milt flowing freely, together with plankton-net collections of newly-spawned eggs indicated sardines were spawning. The summarized behavior observations and collections of fish and eggs are documented in this report.

Both observations and collections were made while investigating late-summer (August-September) spawning of sardines off central Baja California. This secondary spawning period has occurred with some regularity in past years in addition to the species' usual spawning period between February and June. Investigating late-summer spawning has been part of a continuing census of sardine egg and larval populations, a facet of the California Cooperative Oceanic Fisheries Investigations (CalCOFI).

BEHAVIOR

Sardine activity began immediately after dark throughout the bay. The school was spread in a loose aggregation at or near the water's surface. Individual fish darted about apparently at random, and often leaped clear of the water causing the surface to present the broken appearance of having pebbles continuously dropped upon it. The sound was similar to that of a rain shower on calm water. A light suspended beside the ship made it possible to observe the fishes' movements to a depth of 3 meters. Their behavior consisted of apparently random excited motion. An individual fish would feed occasionally on organisms attracted to the light, and some were taken there by hook and line; however, none was observed releasing eggs or sperm.

I have discussed the species' schooling behavior with commercial sardine fishermen and others who have caught them for bait. Their observations, substantiated by my personal experience, indicate schooling behavior generally will follow a specific pattern determined by the school's immediate circumstance. The lack of published material on general Pacific sardine behavior makes it desirable to describe some major patterns to contrast with what I have tentatively assessed as spawning behavior.

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A normally moving sardine school is generally crescent shaped when viewed from above. This applies either when the fish are actually seen, or when their presence is indicated by surface disturbances during the day or by bioluminescence at night. The crescent moves with its leading edge convex as a result of individual fish behavior. MacGinitie and MacGinitie (1949: 420) say: ''Sardines possess the interesting trait of orienting themselves so that they are a little behind and to one side of the fish that is ahead of them. This keeps them in rather long and somewhat slender schools.''

This pattern is changed only slightly when the fish are filter-feeding. Their movements are quickened and the gills are flared often to allow water to flow more easily past the gill rakers and out the gill openings. When sardines are particulate feeding the school tends to break up and the movements of individuals are not oriented to those of nearby fish.

Schools occasionally may appear as irregular areas, usually much longer in one dimension and tending to remain continuous instead of breaking up into linearly associated smaller schools.

The schooling pattern of sardines under predator attack differs considerably from other schooling behavior. The school assumes the shape of a pliable sphere which bulges, indents, and flows when attacked. The top of the sphere may be forced completely out of water under pressure of predation. Any fish which becomes disoriented and swims away from the sphere usually is captured immediately. The school reacts toward the rush of an individual predator by opening before the rush and closing behind it, thus making it difficult for a predator to scatter the fish and allowing the school to retain its continuity against further attack. These observations are confirmed in part by Allen (1920) and Fink (1959).

SPAWNING

One-hundred ninety-eight sardines were collected in South Bay by a gill net and hook and line. The gill net consisted of a single piece of $2\frac{1}{2}$-inch (stretched) nylon webbing 30 feet long by 28 feet deep. Two 1,000-watt incandescent bulbs were hung below reflectors off the stern to attract fish. The net, floating vertically, was streamed from either quarter of the ship, then tied off to act as a barrier in the path of fish attracted to the light. After finding sardines in the first haul in spawning condition, net collections were augmented by hook and line fishing.

Fish were caught by hook and line using two types of lures on a light freshwater bait-casting rod and reel filled with 12-pound test nylon mono-filament line. Either a string of six bright shiny No. 8 hooks spaced 4 inches apart, or a patented ''Paulas'' lure was fastened to the terminal end of the line. A Paulas lure utilizes four hooks covered with bright colored yarn treated with an unidentified fish attractant. These hooks also were spaced 4 inches apart. Either string of hooks was weighted with an ounce of lead then jigged slowly up and down under the light. Sardines were somewhat reluctant about striking either bare hook or lure, but did so frequently enough to prove both are useable collection tools.

This collection of spawning Pacific sardines was the largest on record to that time. Clark (1934: 5) stated that during 12 seasons (1919-1931) of sampling commercial sardine catches at San Pedro, only 39 ripe or nearly ripe females were collected. Four ripe female sardines were taken by California Department of Fish and Game personnel from the research vessel, *Yellowfin*, in south Sebastian Vizcaino Bay on May 5, 1950 (California Division of Fish and Game, log of cruise 50Y4, 1950); a ripe female and two ripe male sardines were taken off San Cristobal Bay, Baja California (Miller, 1952); two small samples of spawning sardines were taken in Sebastian Vizcaino Bay in August, 1953 (California Department of Fish and Game, 1953); sardines in spawning condition (73 of 74 males, 25 of 26 females, K.F. Mais, pers. comm.) were collected off Punta Abreojos early in 1954 (California Department of Fish and Game, 1954); and two ripe female sardines were taken in 1958 by U.S. Bureau of Commercial Fisheries personnel while sampling commercial landings at Ensenada, Baja California.

A random sample of 50 of the 198 fish taken in South Bay were measured and aged. Gonads were examined to determine sex and degree of development. Of 43 females, 34 were about to spawn or partially spawned, four were completely spawned out, and five were not in spawning condition. All seven males were ripe. Fish ranged from 187 to 220 mm s.l. and averaged 200 mm. The age composition of the sample was: 2-year-olds (1956 class), 8 percent; 3-year-olds (1955 class) 42 percent; 4-year-olds (1954 class), 44 percent; 5-year-olds (1953 class), 6 percent.

Sardines from the South Bay collection were older than fish taken by boats based at the Cedros Island village cannery. A random sample of 50 sardines caught on August 15, 1958, within Sebastian Vizcaino Bay ranged from 142 to 178 mm s.l. and consisted of 82 percent 1-year-old and 18 percent 2-year-old fish (1957 and 1956 classes respectively). Routine sampling of the catch at this cannery throughout 1958 showed these smaller, younger fish predominated while larger, older ones like those taken in South Bay appeared only incidentally.

After collecting the ripe sardines, samples of planktonic sardine eggs and larvae were taken in a 3-minute (2229-2232 PST) oblique plankton haul with a 1-meter net, from 20 meters to the surface (both oblique haul and net are described by Ahlstrom, 1953:4), and a 10-minute (2235-2245) circular surface haul with the same net in the same area.

The depth distribution of sardine eggs collected in South Bay parallels Ahlstrom's (1959a:140) conclusion that sardines spawn somewhat below the surface. The oblique haul contained an estimated 5,088 eggs, 67 percent were newly spawned (stage I: Ahlstrom, 1943) and the remainder approximately 1 day old (stage VI). In comparison, the surface tow took approximately 7,180 eggs (both tows were fractioned to 5 percent of original size before counting), of which only 3.5 percent were newly spawned, indicating that newly spawned eggs were more abundant somewhat below the surface.

The estimated 3,360 stage I eggs taken in the oblique haul constitute the largest collection of newly spawned sardine eggs to date, in fact, larger than the total of all such eggs previously collected by the CalCOFI program. Only 10 sardine larvae were taken in both hauls.

Miller (1952) utilizing a ripe female and two ripe males taken in April 1952 off San Cristobal Bay, Baja California, stripped 3,000 eggs from the female and fertilized them with sperm from one of the males. The eggs were incubated, hatched, and the larvae developed through the pre-larval stage. Sardine eggs at spawning lack the wide perivitelline space characteristic of all but their youngest stages in plankton collections. Miller followed the increase in diameter of the outer egg membrane (there is no corresponding increase in yolk diameter) from approximately 1.10 mm at fertilization to a maximum of approximately 1.80 mm by 10 hours after fertilization. There was no subsequent increase in diameter. Miller also determined that cleavage began about 1½ hours after fertilization.

Ahlstrom (1943) described sardine egg development from material taken in repeated plankton hauls. Both Ahlstrom's and Miller's egg diameter measurements are presented with like measurements of eggs taken in the South Bay plankton collections (Table 1). The size of precleavage eggs from all three sources compare favorably. The diameters of older eggs showed greater variation; however, Ahlstrom, using more extensive materials than Miller, found an average diameter of 1.70 mm which was intermediate between Miller's value (1.83 mm) and that which I found (1.62 mm).

TABLE 1

Comparison of Sardine Egg Diameter Measurements (all material measured after preservation)

	Hours after fertilization	*Average diameter of eggs (mm)*	*Range in egg diameters (mm)*	*Number of eggs examined*
Precleavage eggs	0–1½			
Ahlstrom (1943)	"	1.20	1.02-1.38	591
Miller (1952)*	"	1.26	1.10-1.41	20
South Bay (oblique haul)	"	1.23	0.97-1.45	104
Developing eggs	10 to hatching			
Ahlstrom	"	1.70	1.35-2.05	ca 1000
Miller	10	1.83	1.71-1.90	10
South Bay (surface tow)	24-26	1.62	1.45-1.73	100

* 0 and 1 hour observations combined.

DISCUSSION

Although the sardine behavior described took place simultaneously with spawning, as evidenced by fish and egg collections, there was no directly observable link between them. Such a link can only be inferred, since the visibility was limited to only 3 meters and the fish spawned somewhere between there and 20 meters. Indeed, John Radovich of the California Department of Fish and Game has indicated (pers. comm.) that he and other Department biologists have observed the behavior described without succeeding in collecting any accompanying evidence of spawning. A recent communication from K. F. Mais of the California Department of Fish and Game reveals that on May 1, 1962 off Santa Catalina Island, biologists aboard the *Alaska* took a 50-fish sample of sardines in an advanced state of maturity, but were unable to collect any spawned eggs because of lack of equipment. He further states that school behavior as seen beneath the light was typical of non-spawning schools in the area where the fish milled calmly in a moderately compact school between 8 and 30 feet below the surface.

Apparently little or no spawning took place the night of August 16 n Southeast Bay, located immediately east of South Bay. Eight sardines were caught there and all were spent. One oblique net haul and one surface tow were taken but only 34 eggs in varied stages of development were collected. The oblique haul collected 841 larvae of varied ages, however.

I wish to acknowledge the assistance of other investigators of the La Jolla Biological Laboratory who helped examine the sardine and egg collections. Gonad condition was determined by J. S. MacGregor, and the developmental stages of eggs collected in the plankton tows by D. Kramer and E. H. Ahlstrom.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 34, NO. 1, PP. 173–184
FIGS. 1–6, MARCH, 1964

BOTTOM SEDIMENTS OF SAGINAW BAY, MICHIGAN[1]

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ronmental Sciences Division, U. S. Army Research Office, Department of the Army, Washington, D. C.

ABSTRACT

ginaw Bay is a southwest extension of Lake Huron on the east shore of the Southern Peninsula of Michigan. shallow-water derivative of the Pleistocene Lake Saginaw. Sixty-one bottom samples were collected on a rid pattern and analyzed physically. Findings were treated statistically. Sediments range in size from large es to clay. Medium- to fine-grained clear quartz sand is common to all parts of the bay. Currents and wave are primarily responsible for both median diameter and sorting distribution patterns. Only a very general orrelation can be established between depth and median diameter. Heavy minerals occur in abundance y and show an affinity to shallow-water areas subject to prevailing currents. Shape also locally determines mineral concentrations. Only general conclusions can be established from roundness and sphericity and oluble content. Increased organic content is correlative with quiet water environments. The shallow-, heterogeneous nature of Saginaw Bay is not conducive to the recognition of sedimentary criteria suitable rrelations in other than a local environment.

INTRODUCTION

inaw Bay, which is an extension of Lake n, reaches southwestward into Michigan ay on the western shore of Lake Huron. bay is approximately 50 miles long and 20 miles wide, narrowing to 13 miles near its e between Sand Point and Point Lookout). The most prominent of several islands bay are: Charity, Little Charity, North, and Katechay. Three islands of lesser ie between Katechay Island and Fish Saginaw Bay has been discussed numermes since the turn of the century in conon with its glacial origin and the Pleistoediments which surround it, but little has ritten regarding the sediments of the bay. se of its shallowness, the appearance of w Bay has changed many times since its in Pleistocene time. Peninsulas, islands, ts have come and gone with the rise and the water level in Lake Huron.

Object of Study

udy was conducted of the areal distribu- sediments and their variations in median er, sorting, heavy-mineral concentration, ess, sphericity, and content of acid solu- d organic carbon as related to the Saginaw dimentary environment. This work was ted as a part of a cooperative limnological carried out by the Bureau of Commercial es, U. S. Fish and Wildlife Service, and chigan Department of Conservation in v Bay in 1956.

Hydrogeography

Lake Huron Hydrographic Chart No. 52 (1955) was used as a base for sample locations and water depths. Variations in temperature, density, and seasonal movement of the bay water are contained in reports by Adams (1937) and Johnson (1958), and are not included in this study. Data compiled by the Bureau of Commercial Fisheries, Ann Arbor, Michigan, show that the bay has a surface area of 1,125 square miles. Calculated on a volume basis, 57.1 percent of the bay has a water depth of 24 feet or less and 34.2 percent has a water depth of 12 feet or less. Maximum depth in the western half of the bay is approximately 46 feet. East of Charity Island the water deepens to 126 feet at the bay entrance to Lake Huron (fig. 1).

Physiographic variation along the shoreline is moderate. In the western half of the bay, incorporating that portion of the shore southwest of Sand Point and Point Lookout, the shore varies from marsh areas to low sand ridges; thus very little relief exists between shore and bay bottom. From Sand Point east to Hat Point the beaches are sandy, but grade rapidly into rocky shores east from Hat Point to Point Aux Barques. The shoreline east of Point Lookout is predominantly sand with a few rocky promontories jutting into the bay. Except for the water behind Tawas Point and a small sheltered area between Katechay Island and Sand Point, the bay is open to direct wave action and currents.

Geologic Setting and History

Following the final retreat of the Pleistocene ice, Saginaw Bay and the land immediately surrounding the bay were covered by glacial Lake

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[1] nuscript received January 30, 1963.

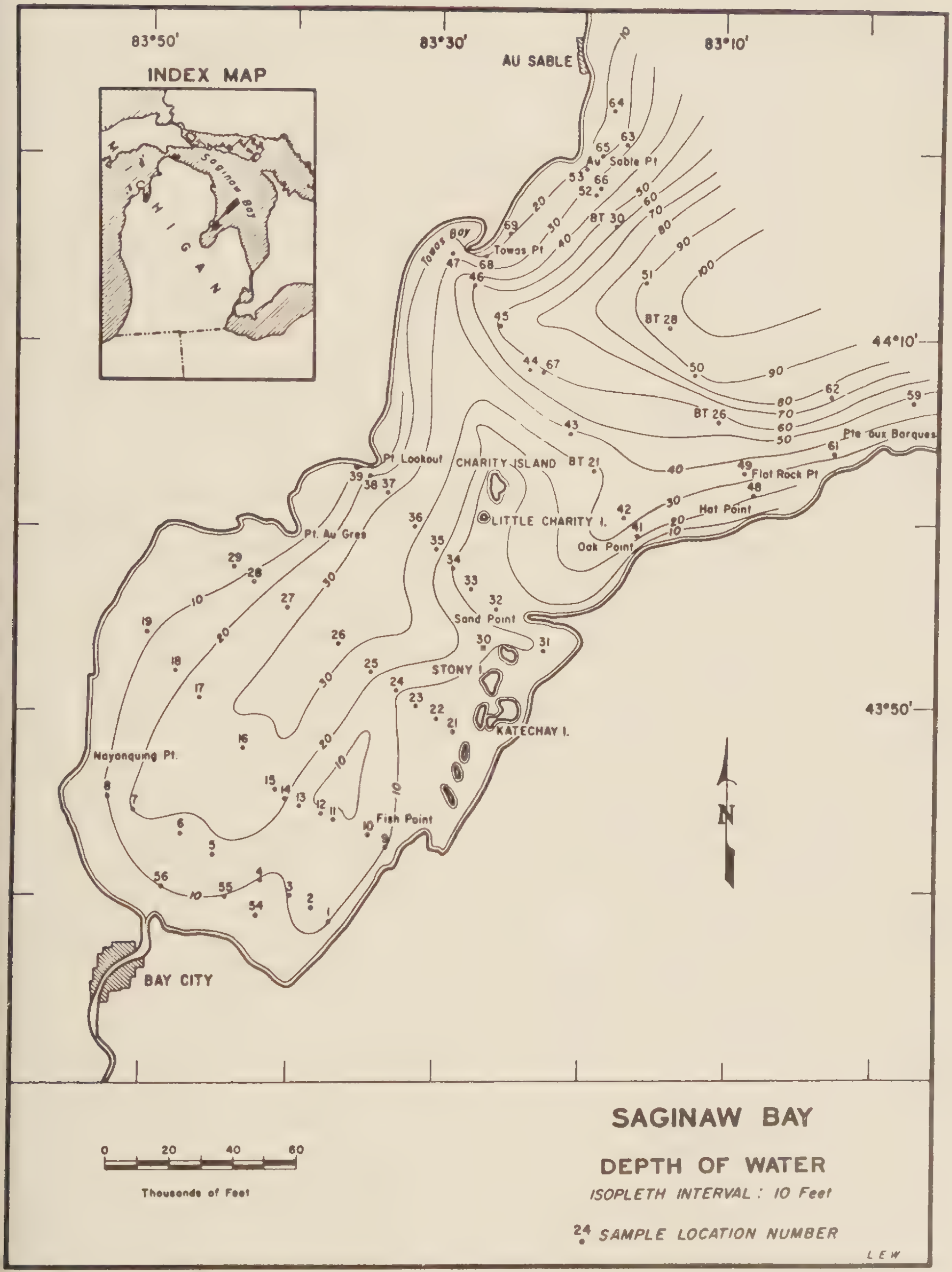


FIG. 1.—Map of Saginaw Bay showing water depth and location of sampling stations.

w. As Lake Saginaw receded to the pres-
nits of the bay an area of low relief consist-
lacustrine sediments was exposed. This
marked by ancient beaches cut by Lake
w and a few low hills which are the rem-
of recessional moraines of the Saginaw ice
Saginaw Bay cuts across the strike of
sippian and Pennsylvanian beds which

dip westward toward the center of the Michigan Basin. As far as can be determined the rocks which form the Michigan Basin are not strongly reflected in the bottom topography of the bay. Bay sediments have been locally removed by currents, and bare rock exposed to wave action. It is not likely, however, that the pre-glacial rocks have contributed much to the present

nents. The main source of sediments is ably the Pleistocene drift which covers the ozoic rocks in the adjacent bay area.

e Saginaw lobe of the Wisconsin glacial shaped the basin for Saginaw Bay, in- ced the present drainage pattern, and pro- water for Lake Saginaw and ultimately aginaw Bay. Spencer (1894) described a pre-glacial river, the Huronian River, in aginaw lowland. This river is believed to flowed northeast across Michigan and en- the pre-Saginaw Bay depression near Bay From here it continued eastward and en- a river flowing in the pre-Lake Huron de- on. That the Huronian River flowed north- and not southwest has not been definitely lished, but it appears certain that at one a river cut a channel in the depression now ied by Saginaw Bay. Northwest-southeast bottom profiles show two distinct channels ding eastward (fig. 2 B, C, and D). The r depression, which represents a channel d by the Huronian River, approximately els the north shore. In the west end of the he channel is wider, shallower, and less lefined. The other northeastward trending el is less prominent than its parallel chan- the north and may or may not be related -glacial drainage. A ridge or shoal, which les Charity Island and Sand Point, is by a northeast-southwest profile (fig. 2A). barrier separates a western basin from a sloping bay bottom which extends to Huron. However, if a line were drawn gh the Huronian River channel parallel to n A, a gradual slope from Bay City to Huron would be apparent.

rounounced lowering of the water level in reat Lakes following the Nipissing sub- of the Wisconsin ice sheet (Flint, 1957) d drainage to the northeast through the ian River depression. The modern Sag- River probably originated at this time and its way into the Huronian channel now in y bottom. The Saginaw is the largest river rging sediments into the bay, and its aries drain a large area in south-central gan. Several small streams with low nts enter the bay, but these contribute little sediment except possibly during thaws and fall rains.

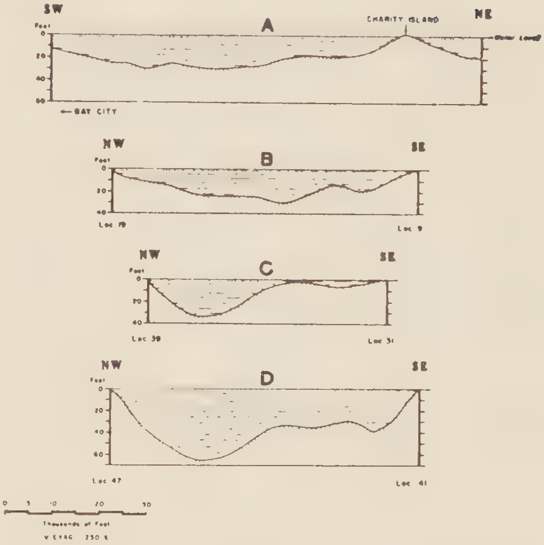


FIG. 2.—One longitudinal (A) and three transverse profiles (B, C, D) which illustrate bay-bottom configuration.

METHODS OF INVESTIGATION

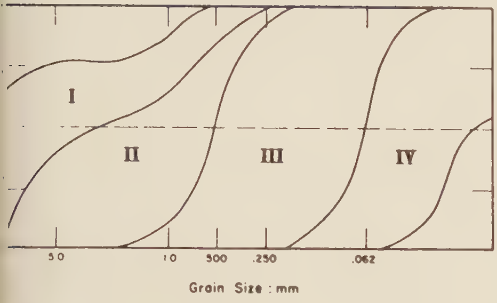
Sample Locations and Devices

61 samples used in this investigation were ed during two summer cruises in 1956 o supplementary cruises, one in October in the vicinity of Bay City, and one in November 1957, off the shores of Au Sable Point and Point Aux Barques. The vessels used included Michigan Department of Conservation patrol boats and the Bureau of Commercial Fisheries research vessels, *Cisco* and *Musky I.* Samples were taken along six northwest traverses which trend perpendicular to the long axis of the bay (fig. 1). Distances between samples along these traverses ranged from ¾ mile in the western half of the bay to as much as 5½ miles near the open end. Distance between traverses ranged from 5 to 9 miles.

A Petersen dredge was used almost exclusively in the 1956 sampling with consistent results. During the later cruses in 1957, a No. 3 Hayward dwarf orange peel dredge with canvas apron proved effective, particularly in the coarser materials. No samples were recovered at locations 4, 44, 57, 58, and 60. It is assumed that at these locations there was either no sediment or the material was too coarse to be picked up by the sampling device. Four cores are included in the study; their locations are indicated by "BT" in figure 1.

Laboratory Procedures

Standard laboratory procedures were followed in preparing and sieving the sediments. The sampled material was air-dried, split, and run through sieves ranging from 6 to 230 mesh. Sediments finer than 230 mesh were then split by the pipette method. Each sediment fraction was weighed and statistical parameters calculated. Several samples contained whole shells or



3.—A composite diagram showing the limits
four types of cumulative curves of sediment size
istribution.

shell fragments. Because of their shape and
these shells remain on the coarse sieves.
use such particles tend to distort the sedi-
ary distribution curve and do not truly
sent the physical environment in which
were found, it was held desirable that
shells or shell fragments be removed before
g. A rule of thumb was adopted similar to
developed by Krumbein and Aberdeen
) in their work on the sediments of Bara-
Bay, Louisiana. They included only those
which were predominantly fragments and
yed a fairly uniform size distribution.
finitions of coarse, medium, and fine size as
here are based on Wentworth's scale (1922).
e—greater than 0.500 mm; medium to
between 0.500 and 0.250 mm; and fine—
han 0.250 mm. Standard procedures de-
d by Krumbein and Pettijohn (1938)
followed in computing median diameter,
g, roundness, and sphericity. Results from
ations of skewness and kurtosis are not
ded in this paper. A linear correlation co-
nt was used in comparing all data, e.g.,
n diameter and water depth, sorting and
n diameter. No significant linear correla-
resulted. Insignificant "F" tests resulted
correlations by analyses of variance in
mparison of the various physical charac-
cs of the sediments among areas. The
ents in Saginaw Bay are subjected to
which vary greatly from one area to
er. This fact emphasizes the lack of signif-
orrelation among the various sedimentary
ydraulic parameters, and further points
e heterogeneity of the sedimentary en-
ment.

IMENT LITHOLOGIES AND DISTRIBUTION

sediments included: large pebbles and
s, coarse sand, fossil corals, shell frag-
from areas of strong current and wave
medium to fine, clear quartz sand throughout the bay; and fine, gray to black silt and clay from undisturbed water. The pebbles and cobbles included a great variety of igneous and sedimentary rocks usually associated with the glacial drift in Michigan. It is difficult to determine whether these pebbles and cobbles were deposited as a result of currents, transportation other than water, or, considering that the bay is of glacial origin, have moved little from their place of initial deposition. Hough reported similar conditions in Cape Cod Bay (1942) and Lake Michigan (1935). Whether the material is a direct result of glacial action, represents an old beach, or has been concentrated by severe wave action since glaciation is not always easily established. A more extensive investigation of the areas of coarse materials in Saginaw Bay is needed before the question of their source can be answered.

The approximate limits of the four prominent size groups and sediment types derived from a composite of the cumulative curves are shown in figure 3. Areas I through IV are representative of the cumulative curves which depict coarse, medium to fine, and silt-size sediments, respectively. Approximately 64 percent of the samples produce a type-III curve which represents a sediment fairly uniform in size distribution from medium-coarse through fine materials, but whose median diameter falls well within the range of 0.500 to 0.062 mm. A high degree of sorting is generally associated with this type of sediment. The type-II curves include some 26 percent of the samples which contain 5 to 25 percent coarse to very coarse material. Sorting is fair to poor. The two extremes in sediment distribution are apparent in curves type I and IV. The type-I curve represents samples in which coarse materials predominate and which have little or no sediment finer than 0.500 mm, whereas the type-IV curve includes those samples in which most of the sediment is finer than 0.100 mm.

A double mode, suggestive of two distinct types of sediment, was evident in a number of these curves. The samples with this distribution were taken almost exclusively from the Huronian River channel. It seems probable that the Huronian River sediments have been preserved in this depression by a thin veneer of recent sediments; both sediments apparently were penetrated by the sampling device.

Median Diameter

Values of the median diameter ranged from near 10 mm in the southwest corner of the bay (southwest of Fish Point) to 0.015 mm southwest of Point Au Gres. The areal distribu-

of sediment according to size is shown in e 4. Approximate percentages of samples in rent ranges were: 57 percent medium; 35 ent fine; 5 percent coarse or larger; and 3 ent silt-size or smaller.

nose sediments coarser than 0.500 mm occur vo narrow bands, each approximately 15 s long, trending parallel to the south shore. zone of coarse material extends from near western shore of Saginaw Bay to a point nwest of Katechay Island. Its sediments be, in part, derived from the islands in that of the bay, but it seems more likely that Saginaw River, during flood stage, supplies naterial. A second zone of coarse sediments nds from near Hat Point to Point Aux ues. Here median diameters average 1 to 5 less than those in the zone near Katechay d. The source of this sediment is probably the rocky shores east of Flat Rock Point.

diments 0.062 mm and finer occur in four y scattered areas. The most prominent is e bottom of the Huronian River depression west of Point Au Gres. A narrow band of fine sediments occurs somewhat erratically the open end of the bay. The reason for an isolated patch of very fine sediments ot be established. It might represent a pre- aw Bay drainage channel. Two small areas ry fine sediments along the southern shore sent zones of current shadows.

nds in the 0.062 to 0.250 mm range cover y half of the bay. They closely follow the nian channel and its flanks as far as ty Island, but then branch into a broad xtending over much of the open end of the The fine sands which occur along the south- hore from Fish Point eastward create a n amount of asymmetry in the sediment oution. This material is probably closely d to the dune sands which have accumulated from a few miles west of Sand Point to a east of Flat Rock Point as a result of ling winds. In a comprehensive report on County, Lane (1900) discussed the area en Sand Point and Hat Point. He attrib- he large accumulation of sand in this area id deepening of water offshore in contrast area from Sand Point westward where is little or no break in profile between ottom and surrounding lowland. From Point eastward, wave action extends to the carrying with it a quantity of sediment. ndertow and littoral currents winnow out e material, thus leaving the sand on the s where it is subsequently carried inland vailing winds to form dunes. Dunes are eveloped between Sand Point and Hat Point; east of Hat Point, however, the shore becomes increasingly less sandy toward Point Aux Barques where the rocky shores are swept by currents.

The remainder of the bay floor is covered by sediments in the medium sand range, 0.250 to 0.500 mm. This grade size covers more than 50 percent of the bay. An elongate hook protrudes from the area of fine sediments in the Huronian River channel in the west end of the bay. It appears at first sight somewhat anomalous, but closer examination suggests that this deposition may be correlated with the southernmost northeast-southwest trough (fig. 2-B) which is deep enough to preserve sediments in the 0.250 to 0.500 mm size range.

Everywhere, with the exception of those areas which lie behind a protecting land mass, the sediments of Saginaw Bay are susceptible to wave or current action. Because of this constant exposure to the forces of waves and currents, a linear correlation between water depth and grain size is not clearly apparent. A general areal correlation is indicated, nevertheless, by comparisons of the water-depth isopleths in figure 1 to the median diameter pattern in figure 4. In local areas, it appears that currents, bottom topography, and shape and density of particles seem to be more important in controlling grain size distribution than water depth. A similar conclusion was established in Buzzards Bay (Hough, 1940) and in Cape Cod Bay (Hough, 1942). Barataria Bay sediments (Krumbein and Aberdeen, 1937) also show a strong dependence on currents rather than depth.

Sorting

Sorting values ranged from log So 0.786 in the southwest corner of the bay in sample 2, to log So 0.072 in sample 69 near Tawas Point (fig. 5). Approximately 70 percent of the sampled sediments were well sorted (log So 0.397 or less) relative to the scale established by Trask (1930). Sixty-eight percent of the sediment distribution, between the 16th and 84th percentiles, was used in calculating sorting, rather than the customary 50 percent. Inclusion of 18 percent more of the distribution curve in the calculation decreased sorting by nearly 50 percent in many samples.

Poorly sorted sediments mark the bottom of the Huronian River channel, whereas moderate to poorly sorted sediments cover the flanks of the depression in a zone extending nearly the full length of the bay parallel to the north shore. A similarly large area of poorly sorted material, which lies northwest of the Huronian River channel, extends from near the mouth of the Saginaw River to Point Au Gres and Point

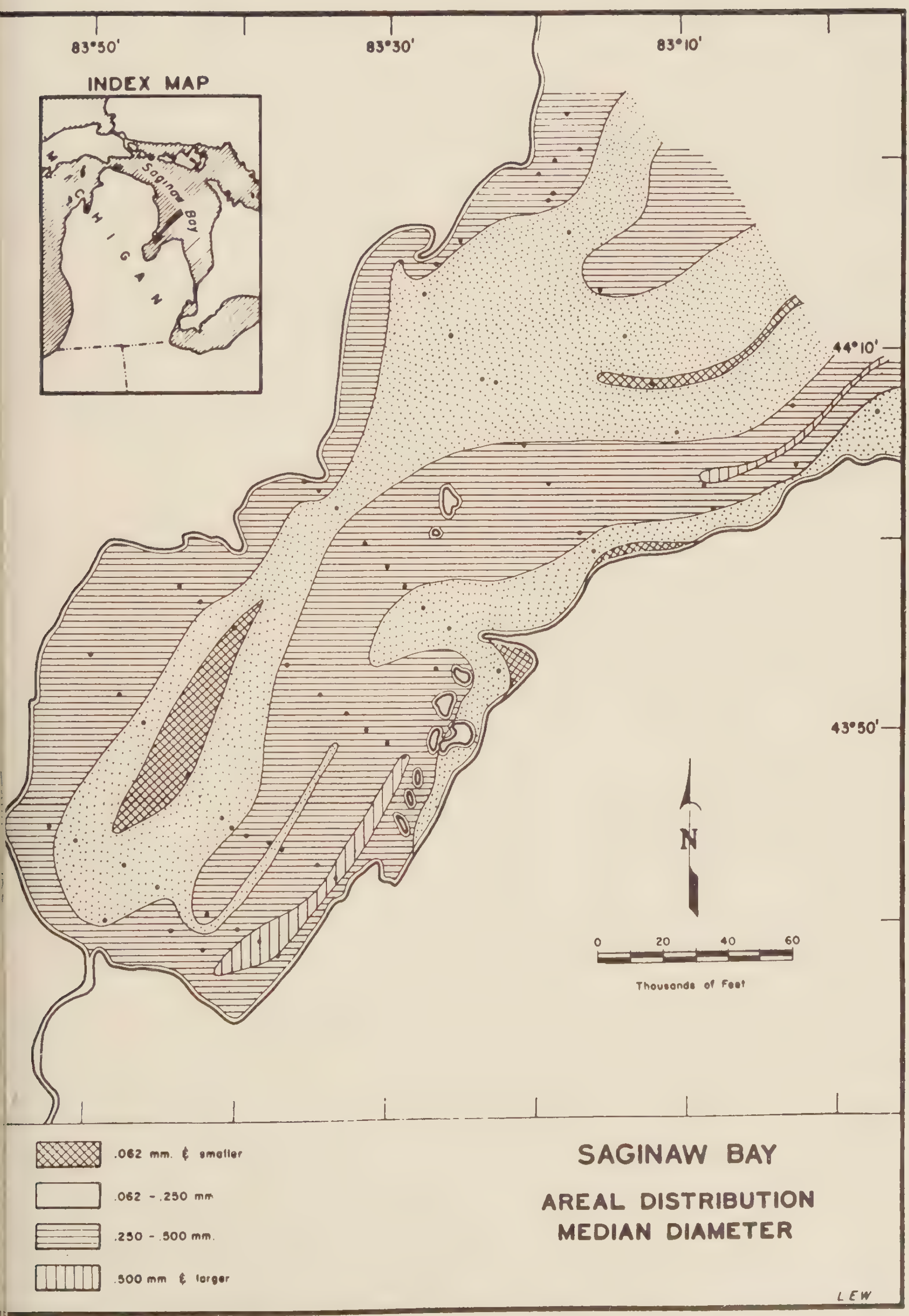


FIG. 4.—Areal distribution of major median-diameter size grades.

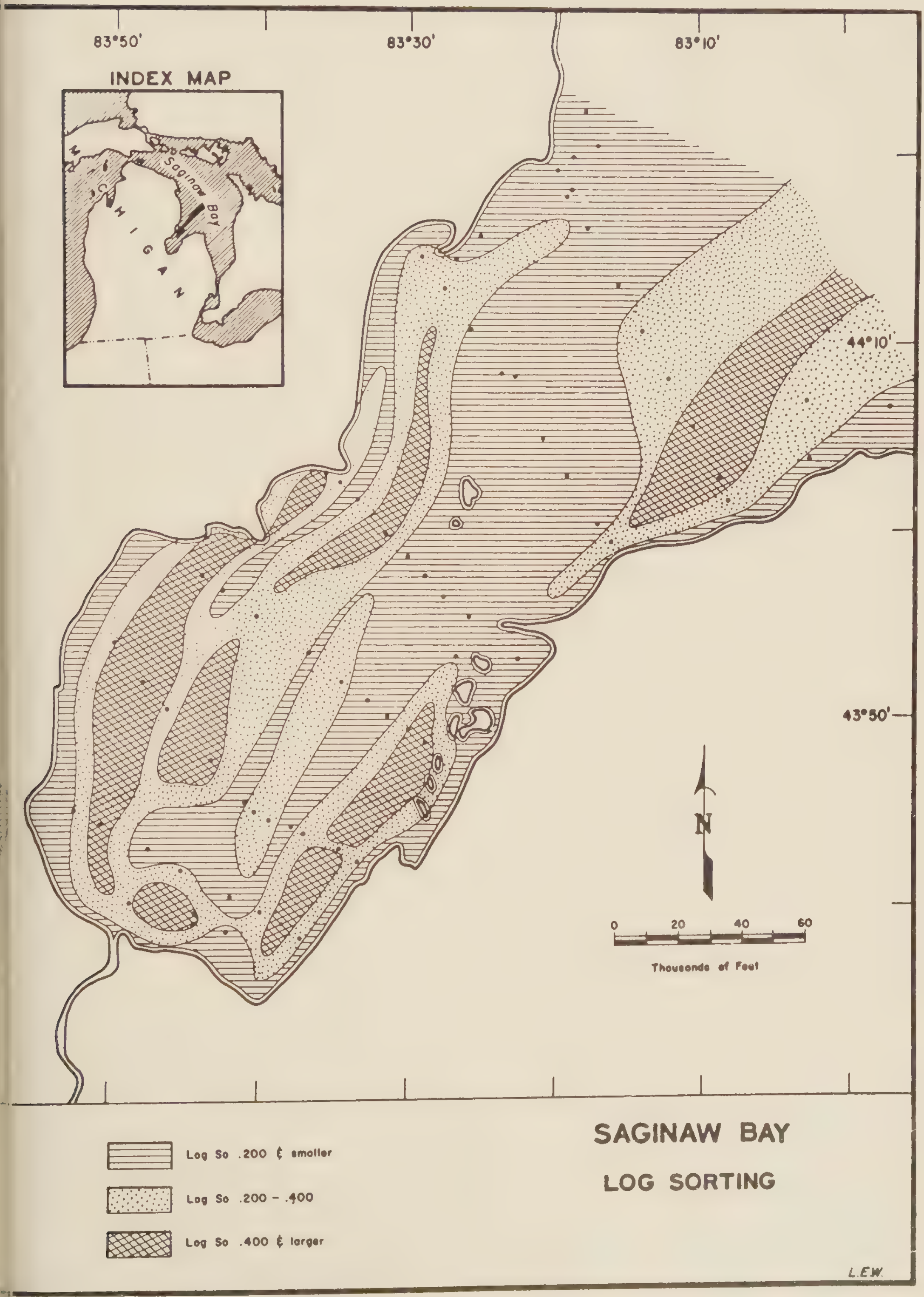


FIG. 5.—Areal distribution of sorting of Saginaw Bay sediments.

kout. This area might be termed "back-
er" which appears, at least partially, to be a
lt of the confluence of southwest-moving cur-
ts around Point Au Gres and the Saginaw
er inflow. A patch of poorly sorted sedi-
nts slightly east of the mouth of the Saginaw
er is further evidence of the meeting of these
masses of water. Sorting was poor also in
rse sediments lying southwest of Katechay
nd and in a rather ill-defined area northeast
lat Point.

he distribution of good sorting, as defined in
re 5, is somewhat complicated. Within the
on of generally good sorting (log So 0.200
ess) lies an area of very good sorting, ap-
imately 15 miles long and 4 miles wide,
ch trends north-northeast through Charity
nd between sample locations 24 and 44. This
ion strongly reflects northeast-moving waters
ch are deflected around Sand Point toward
rity Island.

elationship to grain size.—Sorting of a sedi-
t depends on the hydraulic conditions of a
y of water in which the sediment occurs and
physical properties of the individual grains
hat sediment. It is generally conceded that
ng is best in fine to medium sediments, with
or exceptions which depend on hydraulic
itions affecting the sediment, whereas sort-
s poor in varying degrees toward the fine
ery fine and coarse to very coarse ends of
listribution. Many conditions in nature may
a uniform distribution of particles, that is,
coarse and fine materials together in an
mmetrical distribution. In Saginaw Bay, ice
ng and over-supply of sediment from the
contributing rivers are probably the two
monest causes of such disequilibrium.

diments which have a log-sorting in the
e of 0.100 to 0.200 are most frequent within
ize limits of medium sand. The finer sedi-
s generally exhibit somewhat poorer sort-
the poorest sorting in Saginaw Bay, how-
is in sediments of .0500 mm and coarser.
ths (1951) found a good correlation be-
n size and sorting in a study of some Carri-
unconsolidated sediments, and noted that
relationship was directly proportional to
h of time and "intensity" of deposition.
n the supply of material exceeds the trans-
ng power, the sediments never reach a state
quilibrium through long reworking and
nentary adjustment in a given hydraulic
onment. Thus poor sorting of coarse ma-
s may result from flush-type deposition,
ving short aqueous transport. Analogous
is supposition, a zone in the southwest
r of the bay intermittently receives large quantities of coarse material from the Saginaw River, particularly during flood, as its sediment load is deflected by currents upon entering the bay. This area is not only one of generally coarse, but also one of very poorly sorted sediments. The effect of this deposition may be traced as far east as Katechay Island.

Relationship to water depths.—A linear correlation does not exist between depth of water and sorting. Most of the samples which have less than log So 0.200 were taken from water less than 50 feet deep; on the other hand, a large percentage of poorly sorted sediments occur in water less than 25 feet deep. It may be concluded, therefore, that sorting in Saginaw Bay is only locally related to depth of water in areas subject to constant wave and current action.

Heavy Minerals

A heavy mineral separate was made of 4 grams of sediment split from each original sample. Two size-grade fractions, "coarse" and "fine" were arbitrarily established, between which the 80-mesh sieve (0.177 mm) was used as the dividing line. Separates were made of 2 grams of sediment from each "coarse" and "fine" fraction. The individual and combined weight of residues were then calculated in terms of heavy mineral percentage.

Heavy mineral percentages ranged from 0.6 percent in sample 27 near Point Au Gres to 11.5 percent in sample 8 near Nayanquing Point. Approximately 65 percent of the samples contained, however, between 1.0 and 3.0 percent heavy minerals. Heavy minerals range from 0.05 to 5.4 percent in the coarse fractions, and 1.2 to 22.2 percent in the fine fractions.

The most conspicuous area of high concentration of heavy minerals is a narrow belt of sediments extending from a point approximately 2 miles north of Station 10 (northwest of Fish Point), north-northeast on a line which passes through Charity Island to a point at Stations 44 and 67 north-northeast of Charity Island (fig. 6). Within this slightly "S"-shaped area, percentages ranged from 5.0 at Station 67 north-northeast of Charity Island to 7.8 at Station 34, south-southwest of Charity Island. This concentration of heavy minerals may be attributed to the winnowing of sediments by currents deflected around Sand Point. Isolated concentrations include 5.0 percent heavy minerals in a small area off Au Sable Point, 11.5 percent in a small concentration near Nayanquing Point, and 6.5 percent in a small area at the mouth of the Saginaw River. Although the areas of concentration at Nayanquing Point and at the mouth of the Saginaw River are near each other,

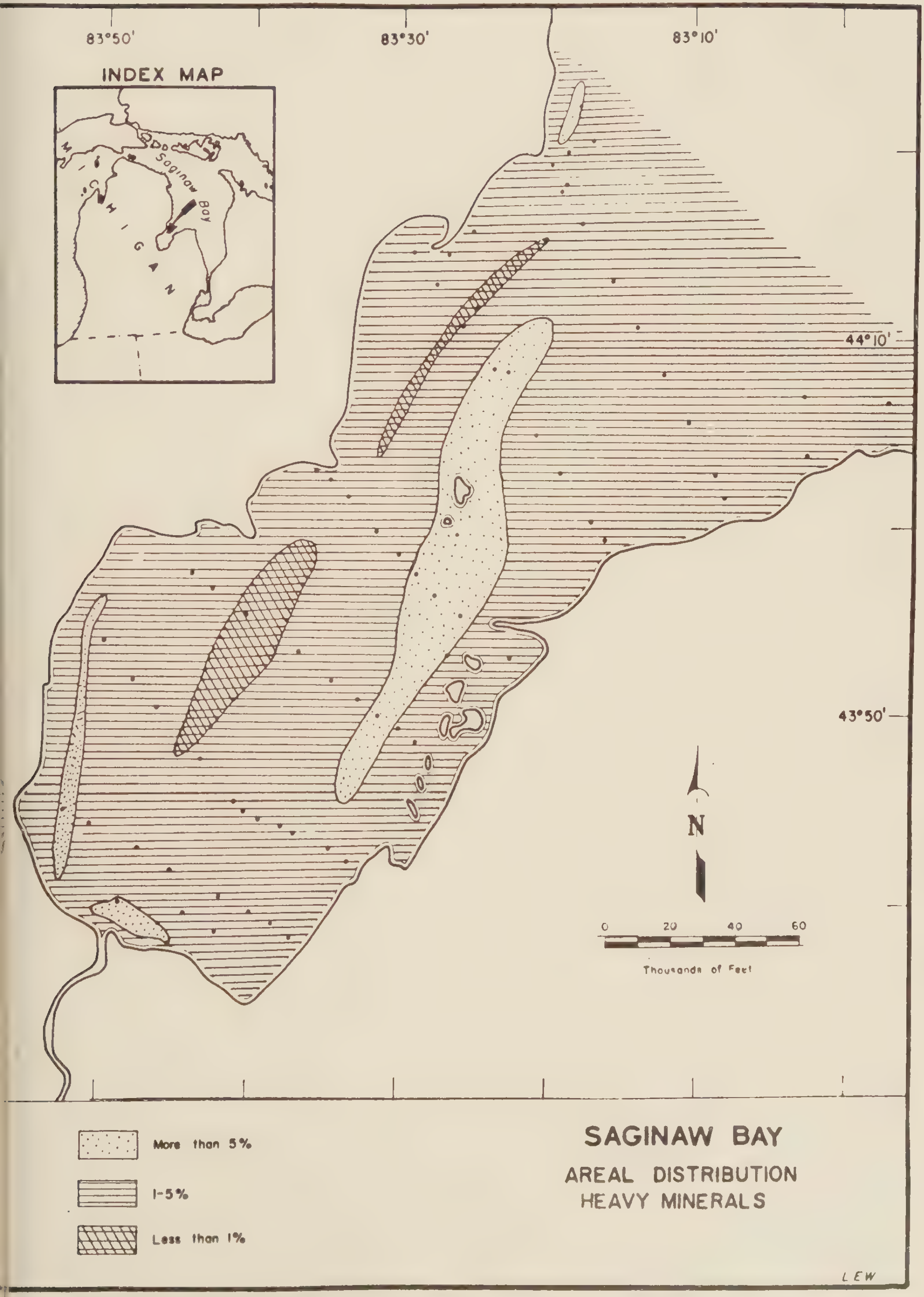


FIG. 6.—Areal distribution of percentage of heavy minerals in the Saginaw Bay sediments.

mmon cause of accumulation can be estab-
d. The Huronian River channel sediments
ained generally less than 2.0 percent heavy
rals.

lationship to median diameter, water depth,
sorting.—No linear correlation exists be-
n the percentage of heavy minerals and
ian diameter. Heavy minerals in accumula-
of over 3.0 percent are restricted to sedi-
ts with median diameters of 0.500 to 0.125
but those sediments containing less than
percent heavy minerals are not restricted in
grain size. The three samples which con-
1.0 percent or less were in sediments with
ian diameters smaller than 0.125 mm. The
entage of heavy minerals did change with
h of water. The higher concentrations oc-
ed in shallow water. Of the 20 samples con-
ing 3.0 percent or more of heavy minerals,
ere taken from water less than 15 feet deep.
road relationship can be established between
ing and heavy mineral percentage. The
centration of heavy minerals was generally
in well-sorted sediments, and low in poorly
ed sediments. Good sorting (log So 0.150
less) was recorded in 70 percent of the
ples containing 3.0 percent or more of heavy
erals; sorting was somewhat erratic, how-
, in the samples containing less than 3.0
ent heavy minerals.

eavy mineral suites.—A suite of 28 mineral
ies was identified in the Saginaw Bay sedi-
ts. Hornblende was present in frequencies up
0 percent, and the metallic opaques, which
ude largely magnetite, hematite, and a small
ntity of ilmenite, occurred in frequencies up
0 percent. Clear garnets, epidote, and white
ques were rarely in excess of 25 percent. Most
spicuously rounded, regardless of size, were
netite and hematite. Grains so perfectly
nded that they resembled shot were common.
s high degree of rounding of the heavier
allics is indicative of abrasion by rolling or
iation, and is in marked contrast to many of
other minerals of lower specific gravity which
prone to transportation by suspension and
w little of no effects of abrasion.

he distribution and concentration of any
en quantity of heavy minerals within a
cific area is, of course, a result of a combina-
of physical characteristics of the sediments
the hydraulic conditions acting upon the
iments. The hydraulic adjustment or dis-
ution of heavy minerals in Saginaw Bay was
ed in comparisons of the more elongate,
ewhat tabular hornblende and the heavier,
l rounded metallic opaques. Almost without
eption, those samples which contained a high
centage of hornblende also contained a low
percentage of metallic opaques and vice versa.

Heavy mineral separates were made of eight river sands in an attempt to determine if individual mineral concentrations were derived from any particular geographic source. It was realized, of course, that rivers which flowed through glacial drift are not likely to reflect any selectivity of mineral suites. Expectations were fulfilled with the minerals occurring in great frequency, that is, those minerals present in nearly equal abundance in every river sampled. Chance omission through sampling or failure to identify is possible in rare minerals; thus their presence in only a few rivers does not warrant their designation as rare unless they are absent in most or all streams. Calcite occurred in amounts up to 5.0 percent in the Pigeon, Sebewaing, and Saginaw rivers which drain the land predominantly south of the bay, but was absent in the Pine, Rifle, Tawas, and Au Sable rivers which drain the land on the north side. No explanation is offered for the difference.

Average Roundness

The areal distribution of average roundness was not well defined. The distribution of several isolated areas of sediments with individually good rounding, for example, was decidedly random. Although the range of average values of roundness was small, the fine sediments from deep water in the western half of the bay were noticeably less rounded than were the coarser sediments. In the deep water east of Charity Island, the grain roundness of the sediments differed considerably from one sample to another.

Roundness and sorting exhibited little or no correlation. Sediments with the highest degree of rounding tended to be concentrated in the center of the bay between Sand Point and Point Lookout where, in general, the sediments were well sorted and the water is shallow. Here again,the currents around Sand Point are probably a factor in the distribution of the rounded sediments.

Average Sphericity

The distribution of average sphericity was poorly defined. Regions of high sphericity occurred randomly at a number of points in the bay. The most conspicuous of them were an oblong area off Point Lookout, a similarly elongate stretch off the shores of Sand Point and Oak Point, and an east-west area at the mouth of the Saginaw River. Although the material tended to have high sphericity in shallow water, equally spherical sediments were found in the deep water at the open end of the bay. Sphericity was related to grain size only in that the very fine sediments definitely lacked sphericity.

he transportation and distribution of grains rding to their degree of roundness and ericity is the result of the adaptation of their e to a given hydraulic condition. Additional sion and reshaping, of course, may take e during this process of adjustment, which s results in further change of the physical racter of the grain. Continued adjustment, efore, takes place until all controlling factors e been equalized and final deposition takes e. Final, or even temporary, disposition of a ntity of sediment, therefore, must be conred in light of the physical character and ntity of sediment being moved, bottom ography, water depth, wave action, and cur- velocity.

Acid Solubles

cid solubles, in amounts ranging from 0.08 .69 percent by weight, were in all samples. r three-fourths of the samples, however, coned less than 0.75 percent acid solubles. Detricalcite, dolomite, and shell fragments conuted the main source of carbonate. In the between Sand Point and Fish Point, enpassing the islands, the protected water dily south of Sand Point, and the channel ch lies along the northwestern edge of the nds, the sediments contained acid solubles ging from 0.6 to 2.0 percent. The source of carbonate seems to be the concentration of hwater mollusks in the shallow water surnding the islands. The effect of this shell centration may be traced in the form of ute fragments and a continuation of high l-soluble content in the near-shore sediments ar east as Flat Rock Point. The Huronian er channel and its flanks include sediments acid solubles in excess of 1.0 percent.

elationship to median diameter and sorting.—ples from the western half of the bay in s of generally fine-grained sediments had tively high acid-soluble content. This aculation was conspicuous in samples adjacent he trench of fine sediments; if, however, all samples taken from the bay are considered, ecomes apparent that the acid solubles are generally a function of median diameter. Any elation that exists between fine-grained sedits and high content of acid solubles may be ibuted to fine shell fragments accumulating reas of deep or undisturbed water. Furthere, the correlation between sorting and acid bles is only slight. A low percentage of acid bles was determined for the well sorted sedits, and a high percentage was, to some ext, prominent in the poorly sorted sediments. source of the acid-soluble material appears be the greatest factor in determining its distribution even though some acid-soluble materials are probably sorted locally according to the physical properties and environment of the sediments in which they exist.

Organic Content

Organic content in the Saginaw Bay sediments range from 0.08 to 7.87 percent by weight. Of the 61 samples examined, however, 44 contained less than 1.0 percent organic matter, and only 6 contained more than 3.0 percent. Organic matter was extremely scarce in the eastern half of the bay within an area outlined by the 40-foot depth contour (fig. 1). Here, organic carbon was as low as 0.08 percent, and did not exceed 0.8 percent. Organic carbon in the Huronian River channel ranged from 1.0 percent on the flanks to 6.4 percent near the center of the trough. The organic content was up to 3.0 percent in a narrow band of near-shore sediments from Fish Point to Point Aux Barques; the greatest concentrations occurred from Sand Point east to Hat Point, and from Sand Point west to Katechay Island.

Relationship to median diameter.—The areal distribution of grain size and organic content were broadly correlated. A few small areas ran contrary to this relationship, but their existence may be explained by the presence of low-gradient streams which are supplying only very fine organic material whose source is the lacustrine soils surrounding the bay. In general, organic carbon has nearly the same specific gravity as water; thus, undisturbed water is essential for complete settling to take place. A significant factor in the correlation between organic carbon and fine sediments is the tendency for fine sediments to enclose the organic matter and protect it against oxidation more than would be possible in coarse-grained sediments (Kuenen, 1950). The coarse sands also offer greater permeability which allows water to circulate freely and introduce oxygen into the deposited materials. Organic matter is therefore easily decomposed and carried away.

Relationship to water depth.—The same correlation between depth of water and grain size applies to depth of water and organic content. The same factors which cause fine sediments to be deposited in shallow water hold for the deposition of organic matter. The correlation is only general because of the disturbing effects of currents, wave action, bottom topography, and sediment characteristics.

CONCLUSIONS

The main sedimentary features in Saginaw Bay closely correspond to the gross current

ls. The adjustment of median diameter,
ng, roundness, sphericity, and other sedi-
ary properties to hydraulic conditions re-
the main current movement which enters
bay around Au Sable Point and approxi-
ly parallels the shoreline until it exits again
Lake Huron around Point Aux Barques.
ly, the direction of flow may be reversed,
he general pattern remains nearly the same.
salient features are altered locally, however,
result of prevailing winds, river influence,
ace physiography, and bottom topography.
se local deviations may in some way be re-
l to the Saginaw River, the Huronian River
ession, or the numerous islands and promon-
s which tend to deflect the main current
ses. Daily or seasonal variations, of course,
not readily perceptible in a one-time sedi-
tary study. Local areas which clearly do not
bit yearly average currents as adjusted to
nanent physical forces, therefore, probably
affected most importantly by changes in
y wind variations and seasonal fluctuations
he volume of river flow.

tudies of recent sediments indicate the
tence of certain laws of sedimentary deposi-
applicable to ancient environment. Rarely
uniform conditions found which produce
grained deposits in deep water farthest
their source, a transition from coarse to
sediments according to depth and distance
source, and sorting according to distance
source. Yet, if the variables to which
osition adjusts are established, and the char-
ristic deposits found under a given condition
determined, a sedimentary environment may
be understood. The distribution of sedi-
ts is not uniformly predictable even under
most favorable conditions as many irregu-
ties affect the final deposition. These vari-
s—currents, bottom topography, surrounding physiography, and the amount, texture, and shape of sediment—have effects that are most difficult to define in a physically heterogeneous shallow body of water such as Saginaw Bay. Here constant adjustments are made to the forces which differ sharply from one area to another. It is, therefore, impossible to relate clearly any one given sedimentary characteristic —physical or chemical—to a force or condition and interpret it as typical for anything other than local environment. In view of this situation it is small wonder that the true nature of ancient sedimentary environment offers such perplexing problems.

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THE BIOLOGY OF ALASKA COMMERCIAL SHRIMP

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A thorough knowledge of the biology of the pandalid shrimp of commercial importance is needed for the sound management of the fishery.

Information on the biology of shrimp is being obtained by sampling with 1/2-meter and high-speed plankton nets for the larval stages and with pots and small otter trawls for the adults.

When the techniques for marking shrimp are perfected, they will be applied to the study of the population dynamics of the shrimp.

The basic life history features of the five species of commercial shrimp are similar: the eggs are carried by the female until they hatch in the spring; the larval shrimp are found in the plankton in the fall; the young adult shrimp appear in the fishery in the winter.

The pandalid shrimp are protandrous, appearing in the adult form as males and changing to females in their second year. Some individuals, however, appear to be females throughout their adult lives. The life span appears to be four years, but only a few females reach that age.

The investigation into the biology of the commercial species of Alaska shrimp has been under way only a year. The basic life history information available from this research and from previous Canadian research is far too limited to provide a basis for the sound management of the fishery.

Laboratory Studies of Shrimp Tolerances to Salinity and Temperature

Z. P. ZEIN-ELDIN AND D. V. ALDRICH
Bureau of Commercial Fisheries, Galveston, Texas

Abstract

Two types of study—24-hour survival and 30-day growth—have been used to test the combined effects of salinity and temperature upon acclimated grooved postlarval penaeids (brown or pink shrimp). The 24-hour survival tests, conducted over ranges of 45 to 98F and 2 to 40 parts per thousand (ppt), indicated that postlarvae had wide tolerance limits to both factors. One hundred per cent of the postlarvae survived all combinations of 68 to 90F temperatures with salinities of 5 to 37 ppt. However, 100% mortality occurred at salinities of 5 ppt or below when temperatures were above 95F or below 60F.

Survival in growth studies using four temperature levels (52, 65, 77, and 90F) combined with five salinities (2, 5, 15, 25, and 35 ppt) was quite similar to that seen in the 24-hour work except for somewhat greater mortality at 90F. Postlarvae held at 2 ppt died within 20 days at all temperatures below 90F. The greatest observed growth of 1.0 to 1.1 mm per day was attained by postlarvae held at 90F. Postlarvae at 77F grew approximately 0.8 mm per day and those at 65F only 0.3 mm per day. Essentially no growth was observed in postlarvae held at 52F. Measurement of food intake indicated that rapid growth required 2 to 3 grams of food for each gram increase in weight.

Survival data indicate that these grooved postlarval penaeids were able to withstand wide fluctuations of both salinity and temperature. Growth also occurred within a wide salinity range, but was restricted to a much narrower temperature zone than that at which good survival was observed. Although growth rate was apparently affected more by temperature than salinity, higher salinities may be more favorable than lower ones as the temperature limits are approached. Both the tolerances and the food requirements would seem to be of considerable importance to the animals in the estuarine phase of its life history.

Effects of Light and Moon Phase on the Behavior of Pink Shrimp[1]

RICHARD L. AARON AND WARREN J. WISBY
Institute of Marine Science, University of Miami
Miami, Florida

Abstract

This particular study deals with responses of the pink shrimp to light of low

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[1] Contribution No. 532 from the Marine Laboratory, Institute of Marine Science, University of Miami.

Proceedings of the Gulf and Caribbean Fisheries Institute,
Sixteenth Annual Session, November 1963, p. 121, May 1964.

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CONCENTRATING PLANKTON IN A GENTLE FASHION[1]

Before starting cultures or enumerating nkton in water samples, one often hes to concentrate the organisms. Tra- ionally, samples have been taken with net or otherwise filtered. Clark and ler (1963) concentrated freshwater phy- lankton samples by vacuum filtration ough a membrane filter, followed by shing the cells off the filter; they re- ted little mechanical damage to the ls. Cells have also been concentrated centrifuging the sample (Wood 1962). While such methods may not damage tain organisms, some of the more deli- e marine forms may be so damaged t they will not grow when transferred an appropriate culture medium, or they y be unrecognizable for identification enumeration. Dinoflagellates are par- larly susceptible to mechanical damage. For instance, neither *Gonyaulax polyedra* nor an oceanic *Gymnodinium* sp. cultured in our laboratory will grow when cultures are shaken, and our *Gymnodinium* loses its motility when centrifuged even at 20 *g*.

Fig. 1 is a diagram of a simple concentrator for plankton that is quite gentle in its action. It consists of a stiff tube of clear Lucite to which a filter is attached.

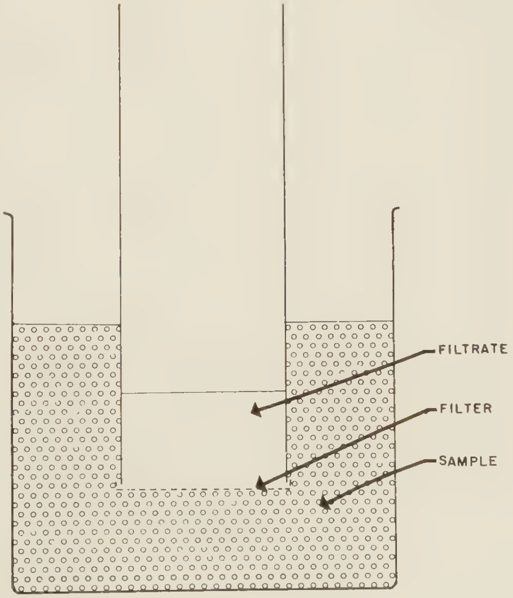

FIG. 1. Schematic drawing of a device for concentrating plankton in a gentle fashion.

Contribution from the Scripps Institution of anography, University of California, San Di- New Series. This research was supported by Marine Life Research Program of the Califor- Cooperative Oceanic Fisheries Investigation; work was part of the Scripps Tuna Oceanog- ıy Research Program of the Scripps Institution Oceanography and the Institute of Marine Re- ces, University of California, and was also ported by Contract No. 14-17-0007-139 be- en the U.S. Bureau of Commercial Fisheries the Scripps Institution of Oceanography. The hors are grateful to Drs. Beatrice Sweeney and ncis T. Haxo, in whose laboratories this con- rating device was initially developed.

We have attached nylon phytoplankton netting using ethylene dichloride as a glue. Filter paper, supported by the netting, may be stretched over the tube and held in place by a wide rubber band. The filter paper is trimmed around the band and adjusted so that, instead of a few wide creases at the trimmed edge, many smaller creases are formed. The trimmed edge is held under the band so that the band seals the filter paper to the plastic tube; thus water cannot flow around the edge of the paper. When membrane filters are used, they are glued directly to the tube with ethylene dichloride. For concentrating larger organisms, zooplankton netting may be similarly attached.

In use, the tube is dipped slowly into a beaker containing the sample. Water flows slowly upward through the filter into the tube and is removed with a large pipette or by gentle vacuum. The rate of flow through the filter can be increased by forcing the tube downward, but for most work dealing with living material the weight of the tube itself is adequate to ensure a steady but nondamaging flow up through the filter paper. Unlike the usual arrangement for vacuum filtration, the flow rate is not dependent on the amount of vacuum applied, and plankton are not subjected to a direct vacuum. Specifically, we have used a tube having a diameter of 11.5 cm and a height of 10 cm. With this tube placed in a 2-liter beaker containing 2 liters of sample and using Whatman No. 42 filter paper, the phytoplankton are concentrated into a volume of 20 ml in 1 hr by the weight of the tube alone.

Phytoplankton penetrate and are embedded in filter paper to a small extent; with membrane filters there is no penetration, and the separation is quantitative. The method was used by Sweeney (1963) to concentrate dinoflagellates prior to testing them for bioluminescence. It was particularly useful in separating large naked dinoflagellates such as species of *Gyrodinium* and *Noctiluca* and thecate forms having large protuberances such as *Ceratium* and *Dinophysis*. Similarly, diatoms with spines such as *Chaetoceros* and *Bacteriastrum* are concentrated with minimal damage.

For measuring the volume of zooplankton in a preserved sample, this device, with zooplankton netting as a filter, is also useful in separating water from the sample with minimum entrapment of delicate spiny Crustacea in the net (R. Griffiths and J. Fee, personal communication).

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C. REPORT ON THE INVESTIGATIONS BY THE UNITED STATES FOR THE INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION—1963

TAGGING STUDIES

by Allan C. Hartt and Michael B. Dell

Tagging by the United States in 1963 was per- rmed by the Fisheries Research Institute, College of sheries, University of Washington, under contract th the U. S. Fish and Wildlife Service, Bureau of mmercial Fisheries.

eld Work

Four purse seine vessels were chartered in 1963: *Commander*, *Renown*, *Ocean Pride*, and *Storm*. Areas igned to the several vessels were:

ommander—area 8050 (Fig. 1)
enown—along 160°W. from the Shumagin Is. to 45°N.
Ocean Pride—along 154°W. from Kodiak I. to 45°N.
Storm—from Kodiak I. to Sitka on approximately 57°30′N.

Vessels fished a series of stations within their assigned areas, attempting to obtain repeated coverage at stations about 50 miles apart. In addition, the vessels fished a few other stations while en route to and from Seattle.

All vessels departed Seattle April 27. The *Ocean Pride* returned August 1, the *Renown* and *Storm* returned August 19, and the *Commander* returned August 26.

Gear used was purse seines and longlines. Seines were similar to those described in earlier years. Longlines were obtained in Japan and were identical to those used in longline operations by Japan and Canada. Salted anchovies as used by Japan and Canada were used for bait in most operations. Early in the season larger-sized California anchovies were tried, but proved inferior. Canadian scientists kindly made available their surplus bait to U.S. vessels, and it is hereby gratefully acknowledged.

Portable tables were built for setting and retrieving the longlines so that both types of gear could be conveniently fished from one vessel. The longlines were used in weather not suitable for seining, thus increasing the amount of fishing time. In some cases both longlines and seines were used for comparison.

Red and white disc tags $\frac{3}{4}''$ in diameter were used on most mature and immature salmon. The very small immature fish that had not yet spent a winter at sea were tagged with the $2\frac{1}{2}''$ long, $^1/_{16}''$-diameter dart tags as described in the 1962 annual report.

A new tool was tried for applying the disc tags. It consisted of a special plier that put a " T-shaped " crimp in the pin with a single motion. The new applicator speeded tagging and standardized the spacing between the tags and the body of the fish. Both features are desirable, and should benefit tag returns. Tagging was also done with the standard pliers so that results may be compared.

Experiments were also carried out in the laboratory with another tool that cuts and rivets the protruding end of the pin on disc tags. This application and the

International North Pacific Fisheries Commission, Annual Report 1963,
Vancouver, Canada, p. 113-121, 1964.

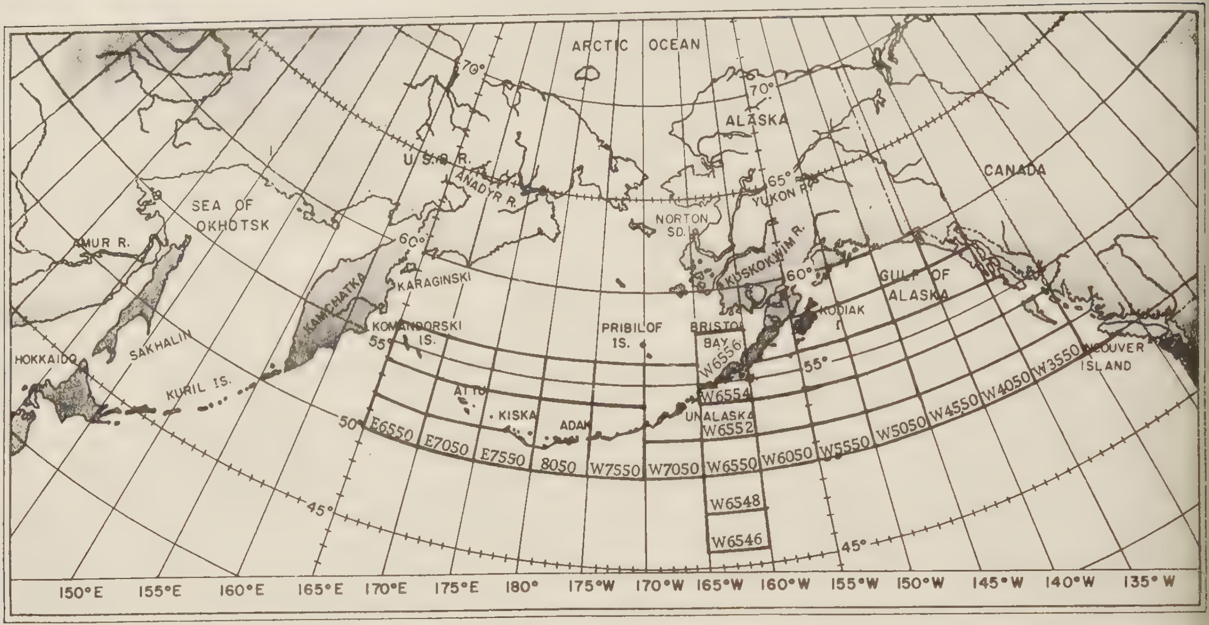

Figure 1. Chart of North Pacific Ocean with key to area code.

" T " crimp are also being tested on trout at a local trout farm. In addition, several types of very small dart tags are being tested on small trout for possible application on 12 to 20 cm. salmon.

Tag recovery effort in 1963 was similar to that of previous years. Posters and tag return envelopes together with letters describing the program were sent to canners, unions and fisheries agencies. Fisheries Research Institute representatives visited nearly all canneries in Alaska. Stress was placed on the importance of the immediate return of recovered tags accompanied by scales and length measurements from marked fish. Printed cards designed to be wired to tagged fish by the fisherman were distributed throughout the canneries. These insured that tagged fish arrived at canneries with recovery information attached. Reward was $1.00 per tag.

In addition, at most major canneries a fee of $2.00 per tag was paid to a designated man for promptly forwarding high seas tags and associated data as they arrived at the cannery. This man was instructed in taking scales and length measurements and was responsible for informing fishermen and cannery personnel of the proper handling of high seas tagged fish. This procedure has proved very effective in obtaining prompt and reliable tag recovery information and biological data. The $1.00 reward and $2.00 handling fee were also paid for Canadian and Japanese tags recovered by U.S. fishermen to insure uniformity in recovery efficiency.

Personnel of the Alaska Department of Fish an Game and of the U.S. Bureau of Commercial Fisherie and of the Washington State Department of Fisheri rendered valuable help in forwarding tags and information. Canada also promptly forwarded information and tags from fish recaptured by Canadia fishermen. Japan sent data on tag recoveries vi wire throughout the mothership fishing season. Th tags themselves were received during the annual meeting in November. Recoveries from the U.S.S.R had not yet been received at the time of writing th report (January 1964).

Objectives

The objectives of the high seas tagging experimen in 1963 were as follows:

1. Central Aleutian Area, *Commander*

Early season operations in the central Aleutian are were designed to compare abundance, timing, an movements of mature salmon of all species with th of previous years. Later operations were primaril for obtaining an index of abundance and age compo tion of immature sockeye salmon for forecasting th 1964 Bristol Bay run.

2. South of Alaska Peninsula, *Renown*

Operations in this area were designed to add ne data on the western limits of Gulf of Alaska salmon and to define better the eastern limits of Asian an western Alaskan salmon. Relatively little taggin l been done in this area in the past.

. Gulf of Alaska, *Ocean Pride* and *Storm*

hese are the same areas as were fished in the Gulf 962. Operations in both Gulf areas were to check distribution, abundance, and movements of mature l immature salmon throughout the season with a v to determining the origin and abundance of non in the Gulf as a whole. All our operations in area were in close cooperation with Canadian ging operations.

bjectives in the central Aleutian area were sati-, although weather considerably interrupted pling. An interesting feature was the early val of the mature salmon in 1963. Significant nbers of mature sockeye, chum and pink salmon e present when sampling commenced on May It is not known how much earlier the migration have begun. A second interesting feature was unusually early appearance of the immature eye salmon. A few were present in seine sets on y 31, and by June 6 both one- and two-ocean-ter immature sockeye salmon were present in tantial numbers. In the past, immature sockeye non have not appeared in numbers until the ration of mature sockeye had declined, usually mid-June. A good series of index sets was ob-ed throughout the period of migration of immature eye salmon between June 6 and August 8, although rather long periods of poor weather caused gaps e data. As in 1962, fishing was tried at different nces from shore, and the optimum distance ap-ed to vary throughout the season from 10 to 30 s offshore.

nk salmon migrated westward through area 8050 bstantial numbers as in previous odd-numbered . Average catch per set between June 1 and 5 was 53 pink salmon. This compares with per set in 1961, 64 per set in 1959 and 458 per 1 1957 during similar time periods.

e *Commander* fished jointly with the U.S. Bureau ommercial Fisheries vessel *George B. Kelez* in area from late June through August 8 to compare ency of gillnets and purse seines, particularly a view to indexing abundance of immature ye salmon.

jectives in the area south of the Alaska Peninsula only partially achieved because of severe weather ations. Several complete series of stations to were obtained, however, and both catches and eturn data should add much to our knowledge of salmon in this area. An interesting stratification of sockeye and chum salmon by size and maturity was evident, with larger mature fish further north, and the smallest immature fish farthest south. Also, coho salmon, chinook salmon, and steelhead trout occurred only in the southernmost stations during May and early June. An unusually large run of one-ocean-winter immature sockeye salmon apparently passed through the Shumagin Island area in early July. Commercial seiners noted substantial numbers in their nets. The *Renown* obtained samples of these fish in mid-July.

Objectives in the Gulf of Alaska were largely realized. Catch and tag release data were obtained by both vessels for comparison with 1962 results. Weather hampered the *Ocean Pride* considerably, but as in 1962, the *Storm* was able to obtain fairly good repeated coverage of her stations throughout the summer. A size and age stratification of immature sockeye and chum salmon was noted on the *Ocean Pride* route south of Kodiak as in 1962. The vessels took small numbers of " 0 " ocean age sockeye and coho salmon along the northern periphery of the Gulf as they returned to Seattle in mid-August.

In addition to their prime mission of fishing and tagging, the vessels collected endocrine tissue samples from immature sockeye salmon at several locations and time periods to furnish material for studying the relationship of endocrine tissue and maturity. These samples were to supplement an endocrine study of smolts and fingerlings being conducted in Bristol Bay lakes.

Numbers of salmon tagged by statistical area and by species are listed in Table 1. Of the total of 10,061 salmon tagged, 968 were from longline catches and the remainder from purse seine catches. Breakdowns by maturity and age have not yet been completed. The total number of salmon caught by the four U.S. tagging vessels was 12,141 (3,986 sockeye, 4,422 chum, 3,410 pink, 166 coho, 115 chinook, 42 steelhead).

Tag returns received through January 1, 1964, are diagrammed in Figures 2–7, and in Table 2.

Figure 2 illustrates the distribution of returns of 38 sockeye salmon tagged in the central Aleutian area in 1963. The 16 returns from Bristol Bay are in accordance with the usual pattern, but the high seas returns indicated some interesting new features of migration.

The 14 returns of maturing fish showed a predominantly westward or northwestward movement with nine recoveries occurring north or south of Kiska Island, two south of Attu, and one far to the north near 180°. In past years the great majority of high seas recoveries from releases south of Adak have been in Amchitka Pass near 180°, or in areas 8052 and 8054 north of Adak. The migration route to Bristol Bay was therefore postulated as being primarily through Amchitka Pass and then northeastward. The 1963 results indicate that at least part of the fish migrated well to the west before entering the Bering Sea. The further swing to the west may be an a occurrence that appeared more pronounced in because of the distribution of mothership effor 1957, 1960 and 1961, mothership effort was greater north of Adak than in the vicinity of during the period that the Bristol Bay run pea the central Aleutian area (INPFC Annual Re 1957, 1960, 1961). In 1963 most effort was of 180°, and there was relatively little effort no Adak as shown in the Japanese section of this a report, and correspondingly only one tag was reco

Table 1. Numbers of salmon tagged by U. S. tagging vessels – 1963.

Area[1]	Inclusive dates	No. of sets	Numbers tagged by species						
			Sockeye	Chum	Pink	Coho	Chinook	Steelhead	To
8050	5/31–8/7	59	1,716	1,807	818	40	15	3	4,3
W7052	8/13–	1	84	87	—	1	—	—	
W6554	7/2–7/19	6	78	22	51	2	18	—	1
W6552	5/30–7/7	4	52	38	5	—	—	—	
W6550	5/17–7/8	11	49	45	43	—	1	—	1
W6548	6/6–7/11	6	38	6	19	—	—	—	6
W6546	5/20–6/7	2	2	4	8	—	—	3	
W6544	5/19–	3	1	20	11	4	1	5	
W6056	6/16	2	3	—	—	—	—	—	
W6054	6/20–7/20	3	5	7	13	—	—	—	
W6052	5/28–7/29	3	22	13	4	—	—	—	
W6050	6/4–7/12	6	91	18	69	3	—	—	1
W6048	5/8–5/23	2	27	3	40	—	—	—	
W6044	6/23–	1	—	—	—	—	—	—	
W5558	7/19–	2	3	7	34	1	1	—	
W5556	5/14–8/6	23	142	129	235	9	24	—	5
W5554	5/8–7/26	15	211	144	95	6	2	4	46
W5552	5/7–7/31	13	55	24	5	—	—	—	8
W5550	5/4–7/28	10	105	105	31	—	1	2	24
W5548	5/17–7/13	12	285	232	21	6	1	3	54
W5546	5/6–7/13	5	6	52	14	16	—	1	8
W5058	6/6–8/8	4	13	7	7	10	—	—	3
W5056	5/15–8/18	30	157	472	93	13	3	9	74
W5054	5/8–	1	16	1	—	—	—	—	1
W4558	8/9–	2	—	—	1	—	—	—	
W4556	5/17–8/19	32	102	319	457	22	4	1	90
W4554	5/5–5/6	4	3	3	—	—	—	—	
W4546	5/3–	3	—	15	1	—	—	3	
W4058	8/10–	2	—	4	49	1	—	—	5
W4056	5/18–8/20	42	41	83	478	9	21	1	6
W4054	5/4–	3	—	7	2	—	—	—	
W4052	5/4–	2	3	2	13	—	—	—	
W3554	5/3–8/14	11	2	11	26	1	4	—	
W3552	8/15–	4	—	—	1	—	—	—	
W3050	8/16–	2	—	—	—	—	—	—	
W3048	8/16–	1	—	1	—	4	3	—	
W2548	8/18–	1	—	—	128	3	4	—	13
	Totals	333	3,312	3,688	2,772	151	103	35	10,06

---

[1] See Figure 1 for area code key.

rth of Adak. The lack of returns of mature fish m west of 173°E. suggests that few if any mature ian sockeye salmon were tagged.

All high seas recoveries of mature sockeye salmon curred between June 11 and 28 with the exception the one of unknown recovery location for which date was given as July 11. Thus essentially all l had time to reach Bristol Bay. Bristol Bay reveries were from July 3 to August 21.

The five immature sockeye recovered by the mothership fleet had migrated considerably westward and northwestward from the release area (dashed lines Fig. 2). In four cases gonad weights at recovery verified immaturity. In the fifth case, length (32 cm.) was sufficient to indicate immaturity. The higher than normal return of immature fish in the year of tagging was probably due to the earlier arrival of the immatures as described earlier. Recovery dates of immature fish were from June 13 through July 27.

Table 2. Distribution of pink salmon returns from Gulf of Alaska tagging in 1963.

Recovery areas	Release areas[1]									
	W5558	W5556	W5554	W5548	W5058	W5056	W4556	W4058	W4056	Total
laska Peninsula (south side)	1	2	2	—	—	—	1	—	—	6
odiak Island	3	19	1	1	—	3	1	—	1	29
ook Inlet	—	—	—	—	—	—	1	—	—	1
ince Wm. Sound	—	14	1	—	1	3	9	—	1	29
y Strait	—	1	1	—	—	1	11	1	19	34
hatham district	—	—	—	—	—	—	1	—	4	5
tersburg	—	—	—	—	—	—	1	—	6	7
ince of Wales Island	—	—	—	—	—	1	6	1	8	16
etchikan district	—	—	—	—	—	—	1	—	2	3
ueen Charlotte Islands	—	—	—	—	—	—	—	—	1	1
ss River	—	—	—	—	—	—	—	—	1	1
eena River	—	—	—	—	—	1	3	—	1	5
ntral B.C.	—	—	—	—	—	—	5	—	3	8
ueen Charlotte-Johnston Straits	—	—	—	—	—	—	—	—	2	2
Totals	4	36	5	1	1	9	40	2	49	147

[1] See Figure 1.

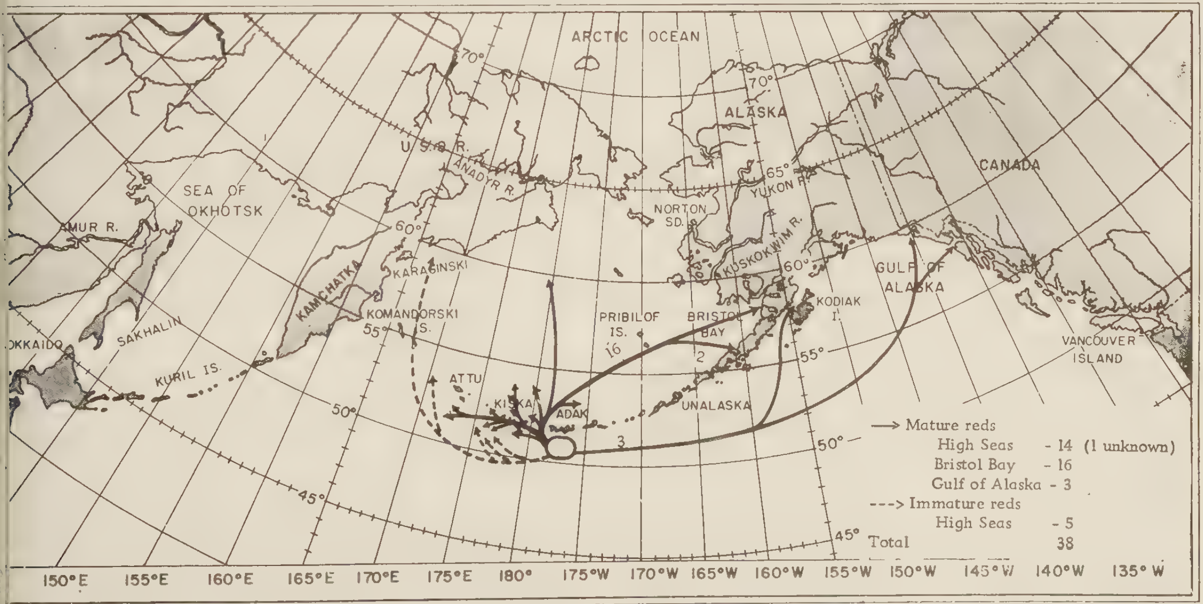

Figure 2. Distribution of returns of sockeye salmon tagged in the Aleutian area in 1963.

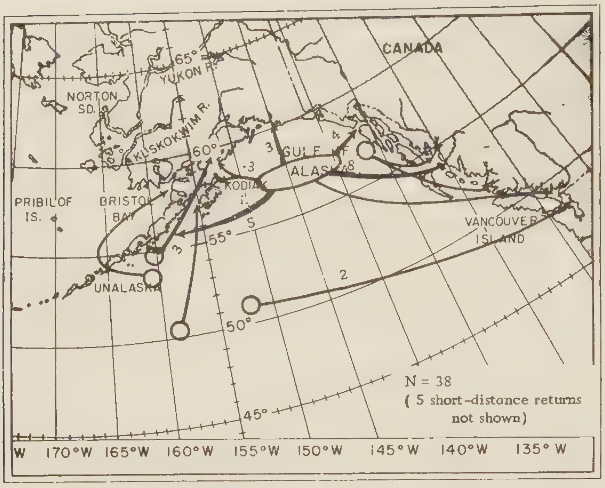

FIGURE 3. General distribution of returns of sockeye salmon tagged in the Gulf of Alaska in 1963.

The three returns from the Gulf of Alaska were unusual, and suggest that there was a higher than normal proportion of mature Gulf sockeye salmon in the Aleutian area in 1963. The two from Southeastern Alaska were the first such returns from U.S. tagging. The only comparable return was a sockeye tagged by Japan about 100 miles south of Adak in 1959 that was recovered in the Nass River, B.C., in the same year (INPFC Annual Report, 1959).

The general distribution of sockeye salmon returns from Gulf of Alaska releases (Fig. 3) was similar to that of previous years. Numbers of mature sockeye tagged and recovered were few, but the wides dispersion from the north-central Gulf, where mature sockeye were tagged, is evident. A complete picture will be obtained when the exte Canadian data are considered together with the data.

Returns in 1963 of sockeye salmon tagged as matures in 1961 and 1962 are illustrated in Figu All were from Aleutian area releases.

The distribution of coastal returns from the releases was unusual. Four were from Bristol and three from Kodiak-Cook Inlet. Although bers of returns were too small for a critical com son, the results do suggest that a higher than no percentage of *immature* Gulf of Alaska sockeye sal were in the central Aleutian area in 1962. As tioned above, tag returns also suggested a high portion of *mature* Gulf sockeye in the central Ale in 1963.

The distribution of high seas returns from 196 1962 releases followed the usual pattern with th ception of the one released in the eastern Ale in 1962 and recovered off Karaginski in 1963 (Fig This specimen may still have been immature w recovered, since it was only 30.5 cm. long when tag The five high seas returns from west of 170°E. (53°N.) were taken between June 3 and 22, sc their coastal destination cannot be inferred certainty. Two of these were still immature as dicated by gonad weights at recovery.

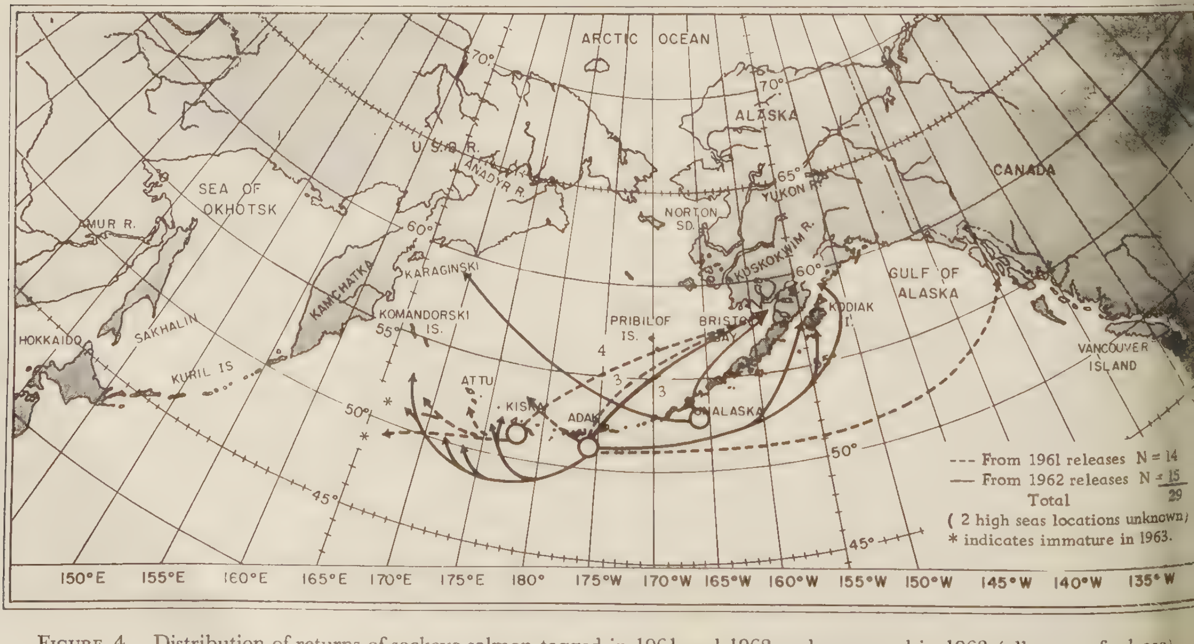

FIGURE 4. Distribution of returns of sockeye salmon tagged in 1961 and 1962 and recovered in 1963 (all areas of release).

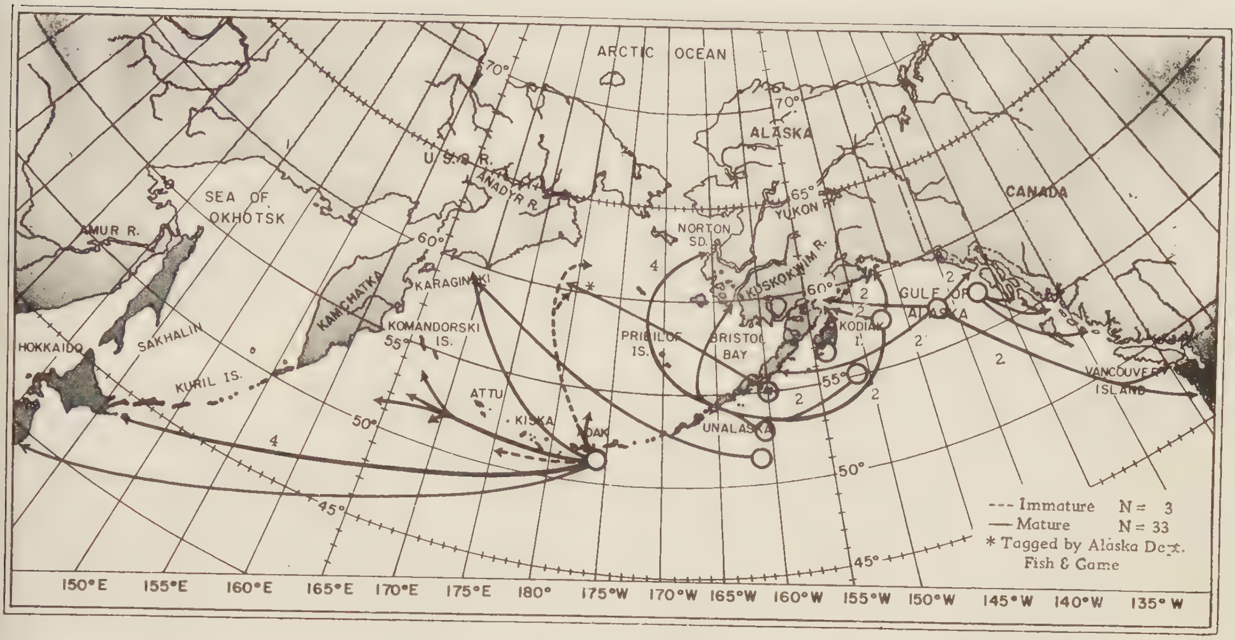

FIGURE 5. Distribution of returns of chum salmon tagged in the Aleutian and Gulf areas in 1963.

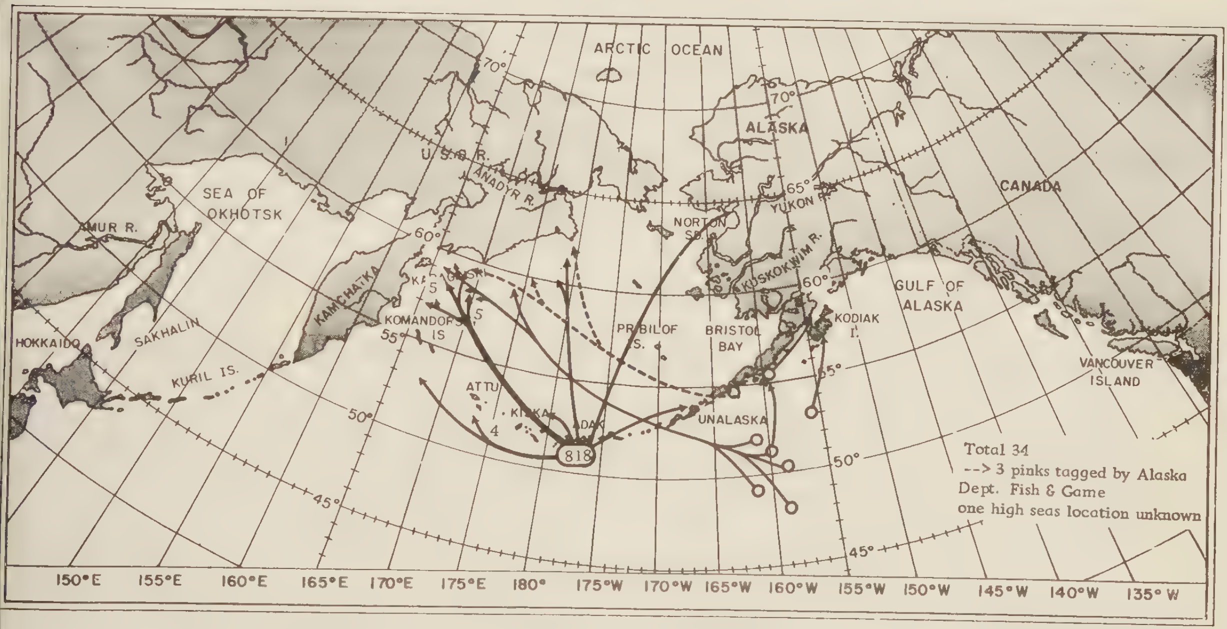

FIGURE 6. Distribution of returns of pink salmon tagged in 1963 (released west of 155°W.).

The lack of returns in 1963 from immature sockeye mon tagged in the Gulf in 1962 is in sharp contrast he Aleutian results as shown in Table 3. Reasons the poor results are unknown. It was not due to erent types of tags, since in both areas the great ority were tagged with dart tags.

The 1963 returns provided data for comparing the ess of return of $\frac{3}{4}''$ red and white discs *vs.* $\frac{1}{2}''$ white discs on one-ocean-winter age sockeye salmon as presented in Table. 4. The $\frac{3}{4}''$ red and white discs apparently have a clear advantage even on such small fish. In earlier years, the return rate of one-ocean-winter age sockeye has varied from 0.3 per cent to 0.9 per cent using tube tags and/or $\frac{1}{2}''$ white discs. Unfortunately an adequate comparison of results from 1962 releases cannot be made because nearly all one-ocean-winter immatures were tagged

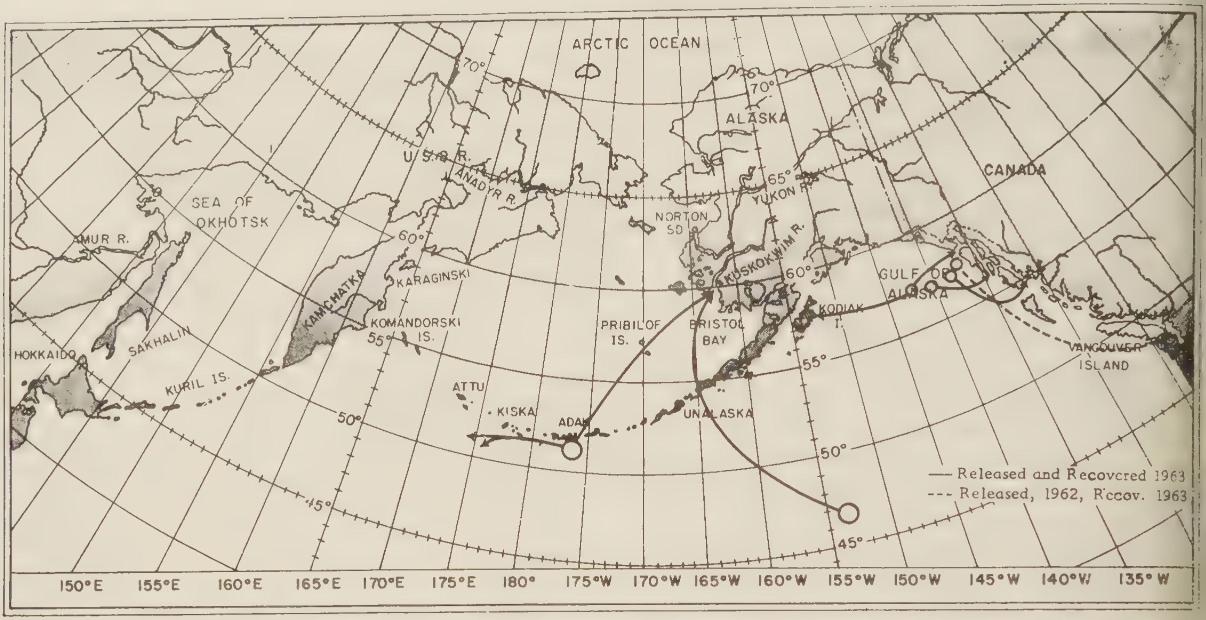

FIGURE 7. Distribution of returns of coho salmon in 1963.

TABLE 3. Comparison of recovery results for immature sockeye salmon tagged in 1962 and recovered in 1963 in the Aleutian area and in the Gulf area.

Age	Aleutian area			Gulf area		
	Tagged	*Recovered*	%	*Tagged*	*Recovered*	%
One winter	908	7	0.8	1,005[1]	0	0
Two winter	415	8	1.9	100[2]	0	0

[1] The one winter age group in Gulf samples included a small but unknown number of jacks (five recovered in 1962).

[2] The number of two winter immatures is a preliminary estimate.

TABLE 4. Comparison of returns of two types of disc tags—one-ocean-winter sockeye salmon tagged in Aleutian area in 1961.

Type of tag	No. tagged	No. returned 1962	% 1962	No. returned 1963	% 1963	Total return	%
½″ white disc	191	1	0.5	1	0.5	2	1.0
¾″ red and white disc	854	24	2.8	13	1.5	37	4.3
Totals	1,045	25	2.4	14	1.3	39	3.7

with dart tags that year. There were five returns of 771 dart tags (0.6%), two returns of 77 ½″ discs (2.6%), and no returns from 50 ¾″ discs. The full recovery picture must await returns in 1964, but it appears that the ¾″ discs used in 1961 give a superior return rate. In 1963 this tag was used on nearly all one-ocean age fish.

Chum salmon returns in 1963 are illustrated in Figure 5. The distribution is similar to that of earlier years. The one released by the Alaska Department of Fish and Game at Popof Head in the Shumagin Islands is of particular interest and probably indica the presence of Asian chum salmon in coastal wat south of the Alaska Peninsula. The specimen wa mature chum salmon released June 16 and recove by the mothership fishery at 61°08′N., 178°52′ E. July 24[1]. The only other such migration dem strated by tagging was that of a chum salmon tag in the Shumagin area in 1923 and recovered East Kamchatka (Gilbert and Rich, 1925).

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[1] Release data from Alaska Department of Fish and Ga recovery data from Fisheries Agency of Japan.

There were only three returns in 1963 from chum almon released in earlier years (one in 1961; two in 962). All were recovered at sea and showed no ew migration patterns.

Additional chum returns are expected from late un areas of Japan and from all areas of the U.S.S.R.

The distribution of pink salmon returns from releases est of 155°W. is shown in Figure 6. Returns from ulf of Alaska releases are presented in tabular form able 2) because of their complex distribution.

The high seas returns from releases in area 8050 ig. 6) indicate that most pink salmon were bound r Asia as in previous odd-numbered years. There ill probably be returns received from East Kamhatka. The one Norton Sound return shows the esence of some North American pink salmon in the ntral Aleutian area in an odd-numbered year. eturns from releases south of the Shumagin Islands ar 50°N., 160°W. extend the known eastward nit of Asian pink salmon from 163°W. to about 8°W. The three returns from tagging by the Alaska epartment of Fish and Game are the first evidence at Asian pink salmon migrate through American astal fishery areas. The three fish were tagged on ne 15 and 23 in East Anchor Cove on the south le of Unimak Island (approximately 54°40′N., 3°10′W.).[1] A number of other returns from Alaska partment of Fish and Game experiments were from estern Alaska.

The results of U.S. operations in the Gulf of Alaska able 2) show only a partial picture of pink salmon tribution because fishing areas assigned to the two ulf vessels covered only the western and northern ulf as described earlier. A more complete picture l be obtained when Canadian results are considered ether with U.S. results. As in 1962, there was a neral mixing of Alaska Peninsula, Kodiak Island, nce William Sound, and Icy Strait stocks through- many of the areas fished by U.S. vessels. Returns m the remainder of Southeastern Alaska and from . were from releases only in the north central and theastern Gulf. No U.S. tags were received from large 1963 run of pink salmon to the Fraser er and Puget Sound, suggesting that these stocks e not numerous in the western or northern Gulf.

he distribution of coho returns in 1963 is illustrated igure 7. The specimen tagged south of Kodiak recovered in the Kuskokwim River extends the known distribution for Kuskokwim coho salmon. The specimen recovered a year after tagging is also of interest. At tagging on July 23, 1962, it was only 29.5 cm. long, indicating that it had migrated a considerable distance northward (700–800 miles), while relatively small, and in a short time, since it had presumably entered salt water in April or May. An additional two coho (not illustrated) tagged near Cape Flattery, Washington, were recovered in the Strait of Juan de Fuca and Puget Sound, respectively.

Laboratory Work

Now that previous years' data have been entered on IBM cards, several new analyses of the data are being undertaken.

In addition, new studies of scales from tagged mature and immature sockeye salmon are being undertaken to supplement the tag return data from several key areas of intensive tagging.

Reference

Gilbert, Charles H., and Willis H. Rich. 1925. Second experiment in tagging salmon in the Alaska Peninsula Fisheries Reservation, summer of 1923. *Bull. U. S. Bur. of Fish.*, Vol. 42 (1926), pp. 27–75. Washington, D.C.

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[1] lease data from Alaska Department of Fish and Game; covery data from Fisheries Agency of Japan.

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January 25, 1964

ERRATA

P. 191 - Line 1. Replace 3, 073 km^2 with 2, 888 km^2.

P. 192 - Line 8. Replace 7. 6 million with 7. 7 million.

P. 197 - Table 1. Top and last lines should read:

321	1. 95	6, 075
14, 630	150. 52	10, 288

P. 198 - Line 5. Replace 97 mm with 98 mm.

P. 201 - Line 17. Replace $r = -.73$ with $r = -.93$.

P. 202. Replace reference 1 with :

1. Catch figures provided by Dr. C. DiCostanzo, U. S. Bureau of Commercial Fisheries, Biological Laboratory, Auke Bay, Alaska.

P. 202. Replace reference 4 with:

4. R. L. Burgner and J. M. Green. University of Washington, Fisheries Research Institute Circular No. 182 (1963).

P. 202. Add reference 10 as follows:

10. Contribution No. 167, College of Fisheries, University of Washington.

ABUNDANCE, DISTRIBUTION, AND SIZE OF JUVENILE RED SALMON OF THE 1960 YEAR CLASS IN ILIAMNA LAKE, ALASKA

Ole A. Mathisen and O. E. Kerns, Jr.
Fisheries Research Institute, University of Washington, Seattle

Introduction

Iliamna Lake (3,073 km^2) is the largest freshwater lake in Alaska and the principal nursery area for juvenile red salmon (Oncorhynchus nerka) in the Kvichak River watershed. The commercial fishery, based on the runs of mature salmon returning to spawn in this district, possesses a cyclic variability. The cycles have changed in length of periods, in amplitude of oscillations, and in number of years constituting the peaks. Over the last twenty years there has been a declining trend in yields.

The cyclic pattern for the Kvichak red salmon is distinct from that of neighboring districts. Since the red salmon from all watersheds in Bristol Bay use common feeding grounds in the ocean, the cause of these cyclic changes will most likely be found in freshwater environment.

The Fisheries Research Institute has conducted studies on the escapements and smolt migrations to the Kvichak system during the years 1955-60 under contract to the U. S. Bureau of Commercial Fisheries, Auke Bay Laboratory, Alaska. In 1961, with funds from a special Emergency Salmon Appropriation, a two-year program was started, which was designed to study in great detail the spawning beds, nursery lakes, and juvenile red salmon in a number of watersheds in Bristol Bay, including the Kvichak system.

Of all the year classes studied to date, the 1960 year class was most significant in that it provided the largest escapement into a single river system on record. Observations on the spawning and progeny of this year class have materially aided our understanding of the internal production mechanism in this watershed. As the final evaluation will have to wait until all the returns are in, this report will be confined to the escapement of the 1960 year class and its progeny through the smolt stage.

The 1960 Escapement to the Kvichak River

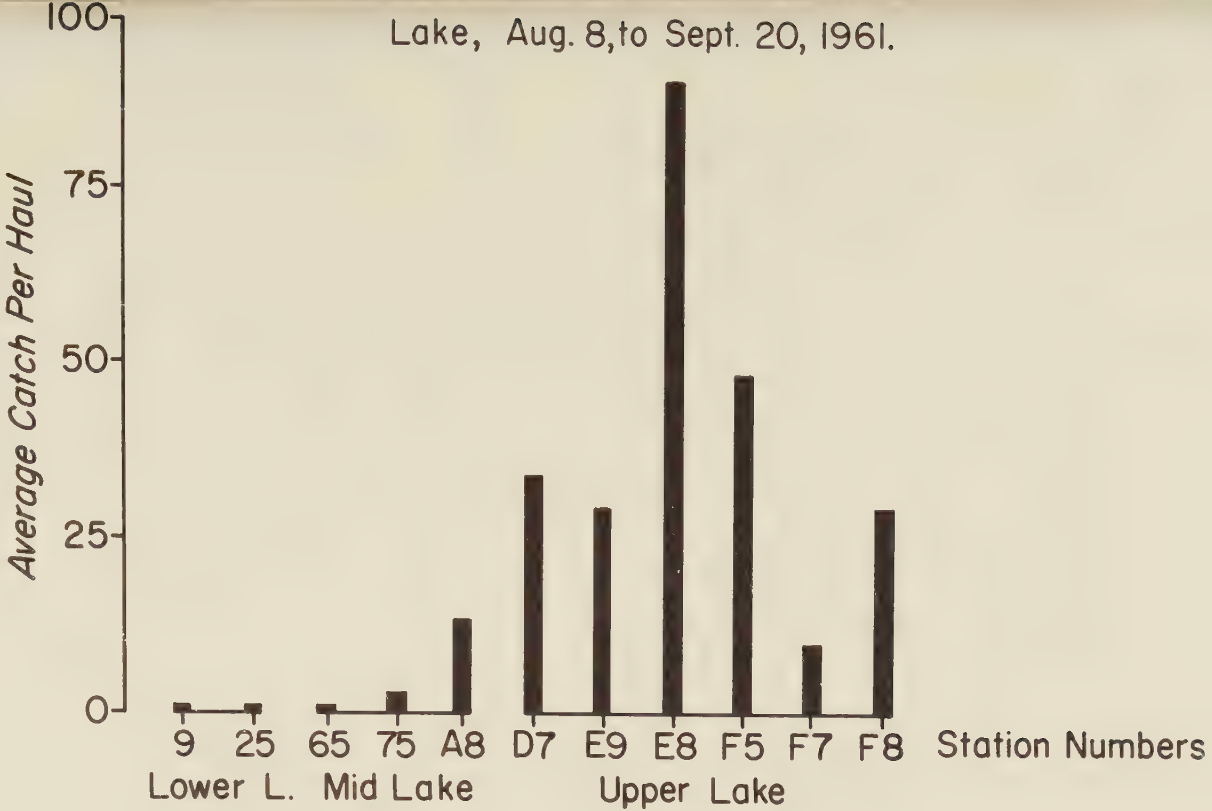
In 1960 the commercial catch of Kvichak red salmon amounted to about 7.6 million fish and the escapement to 14.6 million fish (1). Aerial and ground surveys revealed that over one-half of the escapement returned to the previously known spawning streams while the remainder spawned on defined beaches in Iliamna Lake. Spawning had not been recorded earlier on some of these beaches and spawned-out dead salmon accumulated several feet deep in numerous bays. During surveys in Knutson Bay, scuba divers found beach spawning extending to a depth of 100 feet, with heavy spawning extending to 80 feet. Spawning in other areas was observed to a depth of about 75 feet (2). It appears that extensive and successful beach spawning is associated with peak years in the Kvichak cycle.

Progeny of the 1960 Escapement

In the Spring of 1961, unprecedented numbers of Age 0 red salmon, the progeny of the 1960 escapement, were observed in shallow parts of Iliamna Lake. During the summer, with increase in size, they moved away from the shoreline and could be sampled with an Issacs-Kidd midwater trawl. The distribution observed in August-September 1961 is illustrated in Figure 1, where the catches along the long axis of the lake have been plotted, approximately from the outlet in the west end to the upper bays in the east end (3).

Most of the Age 0 sockeye salmon were captured in the upper sections of Iliamna Lake where the principal spawning grounds are located. Judging from the great variability in average catches made there, no intensive mixing of Age 0

Lake, Aug. 8, to Sept. 20, 1961.



salmon appeared between these sections. The catch in an area often reflected the density of parent spawners. For example, the highest local concentration of fry was observed at Station E8 on Knutson Bay where an estimated one million salmon spawned in 1960.

In 1962 sampling for Age I salmon from the 1960 spawning was made with a 9 x 9 foot tow net developed by Burgner (4) for similar studies in the Nushagak District of Bristol Bay. A total of 212 hauls, each of 20-minute duration, were made in Iliamna Lake between June 15 and September 15, 1962. Towing was made at surface and at 10-foot depth. Distribution and abundance as determined from this sampling in June and July are shown in Figure 2, and those during August and September in Figure 3. Part of the differences in Figures 2 and 3 may be due to sampling variability, but a continued slow drift of the juvenile red salmon toward the lake outlet is indicated. The Age I fish in 1962 were found eventually to utilize the entire lake area, while the Age 0 fish of the same year class the previous year were found mainly in the upper parts of Iliamna Lake.

At the end of August 1962, a striking progression of sizes of Age I fish was found with a mean length of 99.6 mm in the western end and 81.5 mm in the eastern end, or a difference of about 20% of total body length.

Smolt Migration

Based on previous cyclic behavior, 1962 was expected to have a large seaward migration of Age I smolts. However, abundance as determined by catches in a standardized fyke net was only one-third of the previous cycle year of 1958 (5 and 6, and Table 1). To date we have no measure of the absolute number of smolts leaving Iliamna Lake in the spring. A relative measure, expressed as index points, is provided by the catches made in a standardized fyke net. Annual indices are based proportionally on the 1958 smolt catch,

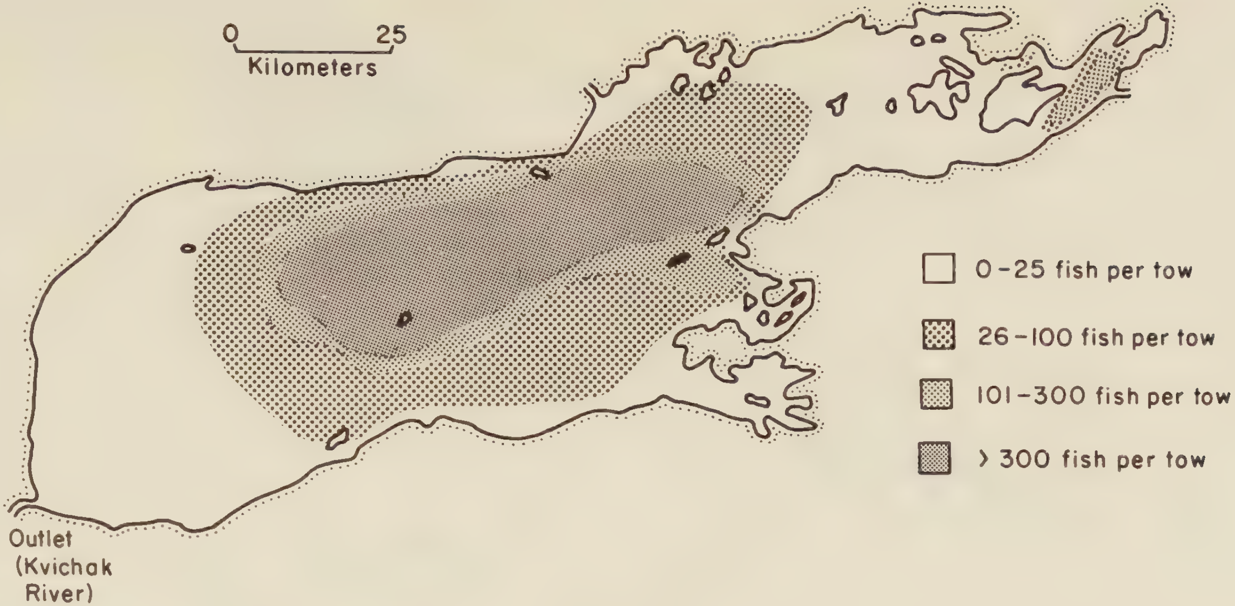


FIGURE 2

Abundance and Distribution of Age I Red Salmon by Mean Townet Catches in Iliamna Lake, June 15, to July 31, 1962.

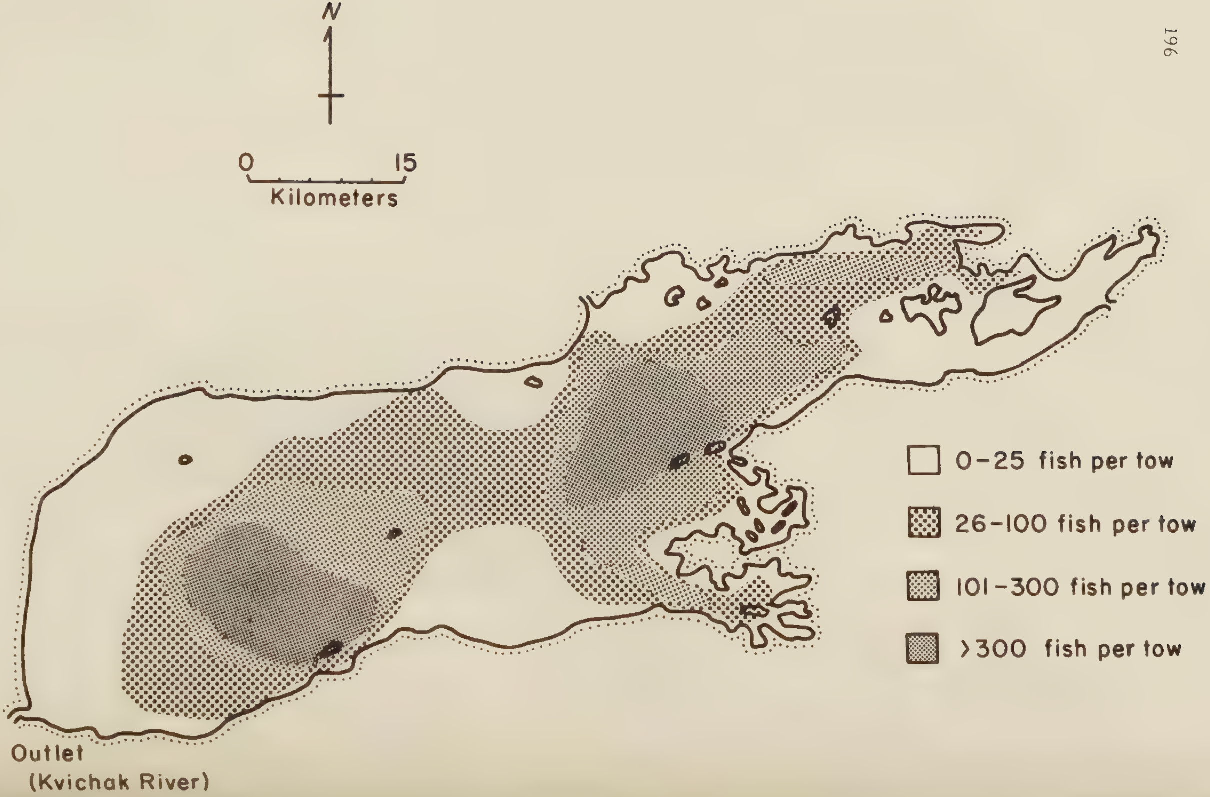

N
0
15
Kilometers
0–25 fish per tow
26–100 fish per tow
101–300 fish per tow
>300 fish per tow
Outlet
(Kvichak River)

FIGURE 3

Table 1. Escapement-smolt relationship, Kvichak River system.

Year of spawning	Escapements in thousands*	Smolts produced, index points	Smolt index points per spawner x 10^{-9}
1953	321	1.95	6,105
1954	241	1.15	4,771
1955	251	2.65	10,558
1956	9,443	181.32	19,202
1957	2,843	19.14	6,732
1958	535	2.15	4,019
1959	680	2.96	4,352
1960	14,516	146.43	10,087

*1953 and 1954 escapements estimated from spawning ground surveys. Later escapements estimated by daily tower counts at Igiugig.

which arbitrarily was given the index value of 100 points. The greater share of the progeny of the 1960 spawning migrated to sea as Age II in the Spring of 1963. More than 98% of the total smolt migration in this year consisted of Age II salmon, which averaged 97 mm in length and seven grams in weight (7, and Table 2).

Relationship of Parent Escapement to Abundance and Size of Smolts

The relative quantity of smolts produced per spawner since 1953 is listed in Table 1.

In spite of the large error we may expect in fyke-net indices of relative strength of the smolt migration, two facts appear evident. In the first place, the highest rate of production of smolts in the Kvichak system takes place during peak years of the cycle. Secondly, the number of smolts produced by 14.6 million spawners in 1960 was less than that which resulted from 9.4 million spawners in 1956. The 1960 escapement therefore appears to be larger than that needed for production of the largest number of smolts. However, because of the relatively small size of the smolts and their short life span in freshwater, it is hardly to be expected that escapement size will be negatively correlated to number of smolts produced except at very high escapement levels. As a corollary, more sensitive indicators are needed in order to define the optimum escapement for this system.

Burgner (8) has demonstrated the immediate and direct effect of spawning density on growth both of Age 0 and Age I juvenile red salmon in the Nushagak District of Bristol Bay. In the Kvichak District the same relationship can be established with a high degree of confidence. From data collected to date on escapement size and average length of smolts produced by these escapements two to three years later, two regression lines can be established (Table 2 and Figure 4). The parent escapement size and mean live length of smolts, Kvichak River system.

Year of spawning	Parent escapement in thousands*	Length Age I in mm	Length Age II in mm
1952	6,000	--	109
1953	321	89	116
1954	241	92	120
1955	251	96	114
1956	9,443	84	99
1957	2,843	80	108
1958	535	91	118
1959	680	93	110
1960	14,630	82	98
1961**	3,706	79	

*1952-1954 escapements estimated from spawning ground surveys.
1955-1961 escapements calculated by tower counts at Igiugig.
**Preliminary data provided by Alaska Department of Fish and Game.

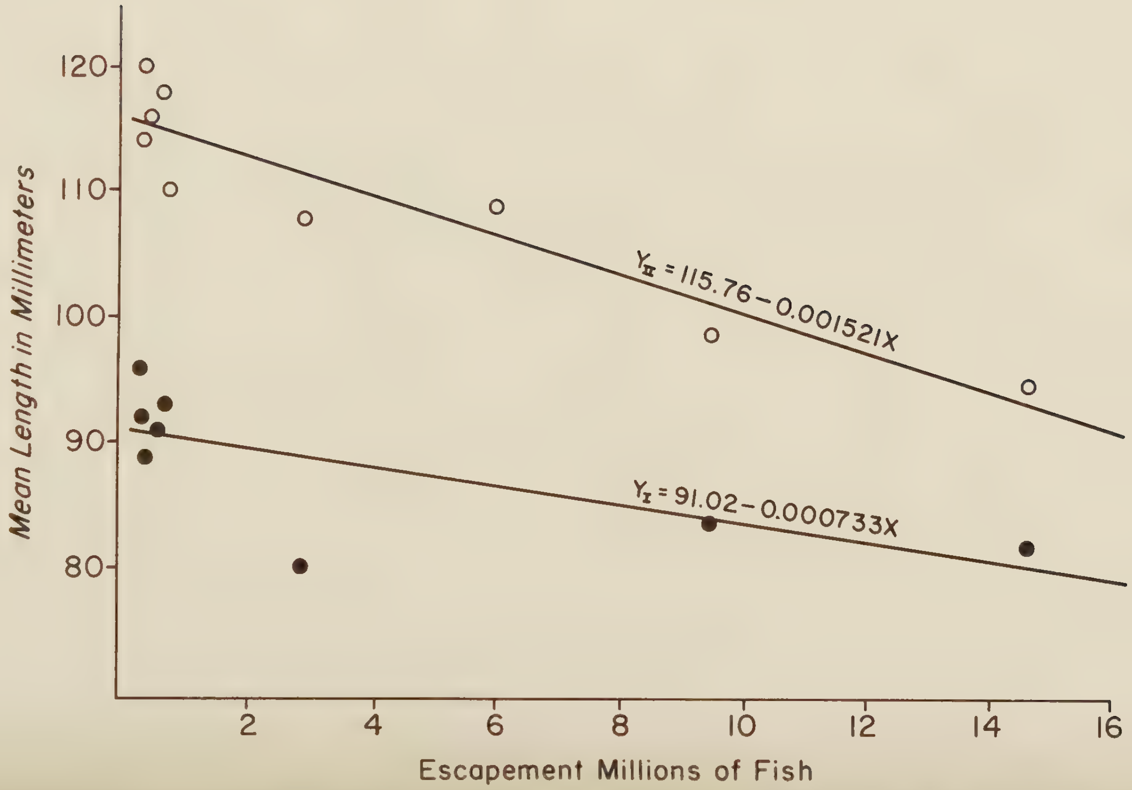

Mean Length in Millimeters
120
110
100
90
80
$Y_{II} = 115.76 - 0.001521X$
$Y_{I} = 91.02 - 0.000733X$
2
4
6
8
10
12
14
16
Escapement Millions of Fish

FIGURE 4

dependent variable, Y_I or Y_{II}, is the length in millimeters of Age I or Age II smolts, and the independent variable is the escapement size, S, expressed in thousands of fish. These equations, as established by least square regression fit are:

$$Y_I = 91.02 - .000733\ S$$

$$Y_{II} = 115.76 - .00152\ S$$

The constants in these equations can be given with narrower confidence limits in the case of Age II smolts since a third peak cycle year, 1952, can be added with an estimated escapement of about six million spawners. Age II smolts from the 1952 spawning were assessed in 1955 during the first year of index fyke netting. All these points, representing escapements ranging from one-quarter million spawners in 1955 to 14. 6 million spawners in 1960, fall closely around the regression line and give a negative correlation coefficient of $r = -.73$.

In the case of Age I smolts the correlation coefficient is lower, $r = -.73$.

Ricker (9) has compiled all available data on ocean survival in relation to smolt size, both from North American river systems and others in Kamchatka, which bring out an inverse relationship between size at migration and ocean survival. Therefore, a second factor to consider in assessing optimum escapement of the peak years of the Kvichak cycle is lengths of smolts in addition to their numerical abundance.

A third factor is the effect of large escapements in peak years upon subsequent year classes. This was first observed after the 1957 spawning when the average size of the resulting Age I smolts was 9 mm less than expected and measured only 80 mm, primarily because these fish spent one year in competition with the numerous juveniles from the large escapement of the previous year.

A similar decrease took place in size of Age I smolts from the 1961 spawning of about 3.8 million fish, which competed with the juveniles from the 1960 spawning of 14.6 million fish.

Conclusions

In judging the effect of a large escapement in the Kvichak system, one must therefore consider not only the number and size of Age I and Age II smolts produced but also the effect on adjacent year classes as well. At the present time insufficient data prevent an exact formulation of all these relationships. In determining the optimum escapement to the Kvichak system, especially for the peak years, we must aim for an escapement which will produce the largest number of smolts of such a size and age that a high ocean survival can be expected. The growth-depressing effect on the progeny of the succeeding adjacent year class must likewise be evaluated.

References and Notes

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CEANOGRAPHIC ASPECTS OF GULF OF CALIFORNIA

BY

GUNNAR I. RODEN

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GUNNAR I. RODEN[2]
La Jolla, California

ABSTRACT

The Gulf of California comprises a large evaporation basin which, at its southern end, is in open communication with the Pacific Ocean. Surface temperatures range between 14°C and 21°C in February, and between 28°C and 31°C in August. Surface salinities fluctuate mostly between $35.0^{\circ}/_{00}$ and $35.8^{\circ}/_{00}$ and change little with season. The amplitude of the mean annual sea-level oscillation observed at tide gage stations is about 15 cm, and agrees closely with that of the steric sea-level oscillation above 500 m. The mean tidal range increases from about 1 m at the Gulf entrance, to 7 m near the mouth of the Colorado River. This river, which is rich in sulfate, sodium, and calcium, has a mean annual discharge rate of 120 m^3/sec. Northwesterly winds in winter drive the surface water southward and cause extensive upwelling along the east coast and in the lee of Isla Tiburón; southeasterly winds in summer move the surface water northwestward and give rise to some upwelling along the Baja California coast. The order of magnitude of the upwelling speed is 3 m per day. In the northern part of the Gulf, winter cooling may lead to convective overturn near the coast that may extend downward to about 100 m. The subsurface circulation in the Gulf is rather complicated. The salinity distribution suggests that there is inflow of low-salinity water along the east coast and outflow of high-salinity water along the west coast, at depths between 50 m and 100 m. Below the bottom of the thermocline, the water in the Gulf is essentially the same as elsewhere off southern Mexico; it is characterized by a salinity minimum of less than $34.60^{\circ}/_{00}$ between 400 m and 800 m, and by an oxygen minimum of less than 0.2 ml/L between 200 m and 800 m. In some instances, the amount of dissolved oxygen was below the titration accuracy (0.05 ml/L). At depths between 2,500 and 3,000 m there is a temperature minimum of slightly less than 1.85°C; from there to the bottom, the temperature increases again, mainly as a result of adiabatic compression. Unusual hydrographic conditions, not found elsewhere in the eastern Pacific, are encountered in Ballenas Channel, which is completely isolated from the rest of the Gulf below 250 m. Here the bottom (1,500 m) temperatures are about 11°C, or about 8°C higher than at comparable depths outside the channel.

INTRODUCTION

The Gulf of California occupies an oceanographically unique position among the marginal seas of the Pacific Ocean. Lying as it does between the arid peninsula of Baja California in the west, and the equally arid states of Sonora and Sinaloa in the east, it comprises a large evaporation basin, which, at its southern end, is in open communication with the Pacific. The moderation effect this ocean upon the climate of the Gulf is great reduced by an almost uninterrupted chain mountains, 1 km to 3 km high in Baja Californi The climate of the Gulf of California is therefo more continental than oceanic, a fact whi contributes to the large annual and diurnal ter perature ranges observed there (Hernande 1923). Topographically, the Gulf can be divid into a series of basins and trenches, separat from each other by transverse ridges (Shepar 1950). Most of the basins are deep and in ope communication with the ocean, although Ballen Channel, between Isla Angel de la Guarda, Is San Lorenzo, and Punta San Gabriel, has no co nection with the latter.

The first hydrographic cruise into the Gulf w made in 1889 by the U.S. Fish Commissi steamer, *Albatross* (Townsend, 1901). This w followed (Table I) fifty years later, by the E.V Scripps cruise (Sverdrup, 1941; Roden, 1958). 1940, rather detailed geological investigations we made in the Gulf (Anderson and others, 1950) a

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[1] Manuscript received, September 1, 1962. Contribution from Scripps Institution of Oceanography.

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TABLE I. CHRONOLOGICAL LIST OF HYDROGRAPHIC CRUISES INTO GULF OF CALIFORNIA

Date	*Ship*	*Hydrographic Casts*		*Properties Observed*	*Area Covered*
		No.	*To Depth*		
ar.–7 Apr. 1889	*Albatross*	28	bottom	temperature, salinity	Cabo San Lucas northward to Colorado River
eb.–19 Mar. 1939	*E.W. Scripps*	53	bottom	temperature, salinity, oxygen, calcium	Cabo San Lucas northward to Colorado River
eb.–17 Feb. 1956	*Black Douglas*	22	1,200 m	temperature, salinity, oxygen	Cabo San Lucas northward to Isla Tiburón
pr.–23 Apr. 1956	*Black Douglas*	40	600 m	temperature, salinity, oxygen	Cabo San Lucas northward to Colorado River
ov.–16 Dec. 1956	*Horizon*	59	bottom	temperature, salinity, oxygen	Cabo San Lucas southward to Isla Socorro and Cabo Corrientes
eb.–23 Feb. 1957	*Horizon*	59	bottom	temperature, salinity, oxygen	Cabo San Lucas northward to Isla Tiburón
pr.–23 Apr. 1957	*Black Douglas*	37	600 m	temperature, salinity, oxygen	Cabo San Lucas northward to Colorado River
n.–23 Jun. 1957	*Stranger*	57	600 m	temperature, salinity, oxygen	Cabo San Lucas northward to Colorado River
g.–26 Aug. 1957	*Stranger*	57	600 m	temperature, salinity, oxygen	Cabo San Lucas northward to Colorado River
pr.–24 May 1959	*S.F. Baird*	47	bottom	temperature, salinity, oxygen	Cabo Corrientes to Colorado River
n.–4 Feb. 1960	*Alaska*	—	—	bathythermograph temperature to 250 m.	Isla Tiburón northward to Colorado River
t.–11 Nov. 1961	*H.M. Smith*	41	bottom	temperature, salinity, oxygen	Cabo San Lucas northward to Isla Tiburón

43 the Mexican government conducted a few
ies for the purpose of establishing a guano
stry there (Osorio-Tafall, 1943). During the
s 1956 and 1957, six hydrographic expeditions
sent to the Gulf by the U.S. Fish and Wild-
Service in cooperation with the California
eries Investigations; the aim was, among
r things, to investigate the seasonal changes
len and Groves, 1959). Since then, hydro-
hic casts have been taken during the *Ver-*
n Sea Expedition in 1959, and during the
gical investigations in 1961. The stations
pied during the 1956–1961 cruises are shown
gure 1.

METEOROLOGICAL ASPECTS

r temperature and precipitation.—Figure 2,
fied from Page (1930), and Ward and Brooks
)), summarizes the areal distribution of air
erature and rainfall in the Gulf of California
djacent regions. It is seen that in winter, the
mperatures decrease toward the interior of
Gulf, and that the temperature differences
een the east and west coasts of Baja Cali-
a are small. Over the adjacent land areas,
eratures depend mainly upon altitude;
r frosts are not uncommon at higher eleva-
and may occasionally occur near the coast
e northern regions. In summer, the air
erature increases toward the interior of the
nd the temperature differences between the
nd west coasts of Baja California are large,
imes exceeding 10°C.

Precipitation in the Gulf is more plentiful on the east than on the west side. The northern half of the Gulf is dry, desert-like, with annual rainfall amounts of less than 10 cm. In the southeastern part, rainfall along the coast increases to about 100 cm per year; here extensive swamps are common. Most of the rain in the Gulf falls between June and October, though winter rainfall is to be expected in the northern third. Over the adjacent land areas, rainfall increases with altitude. Thus, the mountains of Baja California have an average annual rainfall of 25–75 cm; whereas, on either coast of the central peninsula, it is less than 10 cm. The year-to-year variation of rainfall is large and the amounts shown in Figure 2 may differ by a factor of seven in any particular year.

The month-to-month variation of air temperature and rainfall for a few representative coastal stations is given in Table II. It is seen that the mean annual temperature range increases from about 6°C at Cabo Corrientes to 18°C near the mouth of the Colorado River. The number of rainy days per year decreases from about 60 at Cabo Corrientes to about 5 along the central Baja California coast.

Evaporation.—Direct measurements from evaporation pans at coastal stations indicate that the mean annual evaporation ranges between 200 cm and 250 cm per year (Servicio Meteorológico Mexicano, 1928–1941). The minima occur in winter, and the maxima in summer. Though pan evaporation may be indicative of conditions in the immediate vicinity of the coast, it does not neces-

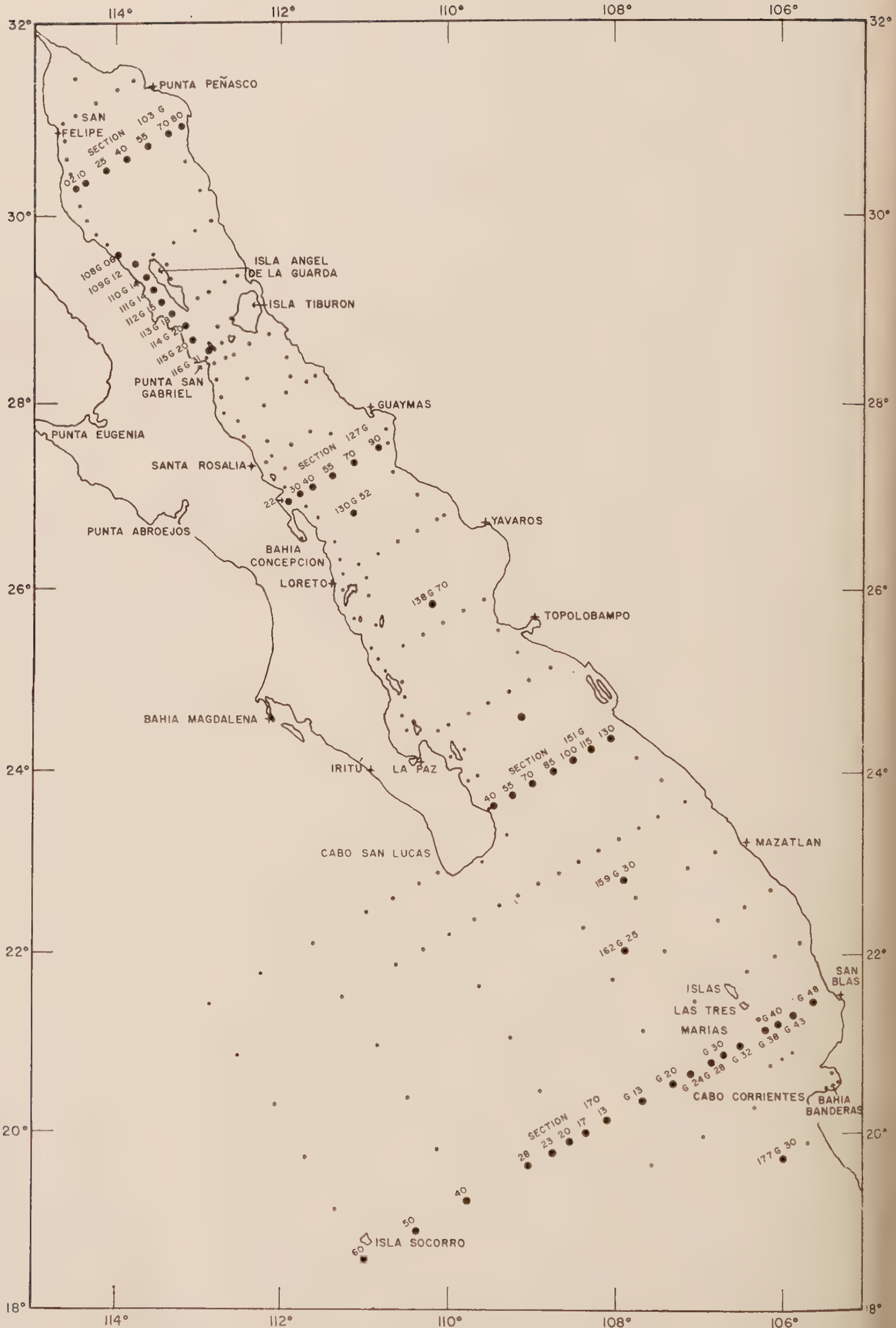


FIG. 1.—Stations occupied during the 1956–1961 hydrographic cruises. Sections and stations used in this investigation are numbered and shown by filled circles.

TABLE II. AIR TEMPERATURE (T) AND PRECIPITATION (P) AT COASTAL STATIONS
(After Servicio Meteorológico Mexicano, 1928–1941)

	I	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	*X*	*XI*	*XII*	*Year*
[1] San Luis, Río Colorado, Son. 32°38′N 114°50′W													
a (°C)	11.9	14.7	18.3	21.5	25.4	29.7	34.4	34.0	30.2	23.8	16.8	12.4	22.7
)	7.1	9.6	4.2	2.6	1.0	0.0	9.5	12.0	5.7	8.0	2.8	14.0	76.5
s)	2	2	1	<1	<1	0	<1	2	<1	<1	<1	1	12
Guaymas, Son. 27°55′N 110°53′W													
(°C)	17.6	19.0	21.0	23.3	26.4	29.1	30.8	30.8	30.2	27.2	22.5	19.5	24.8
max. (°C)	22.6	24.2	26.6	29.1	32.1	34.1	35.2	35.2	34.9	32.3	28.2	24.5	29.9
min. (°C)	12.7	14.1	15.8	17.9	20.9	24.7	27.1	26.9	26.0	22.4	18.2	15.0	20.1
)	7.9	6.3	4.6	3.0	2.8	0.7	46.7	75.5	54.4	9.5	11.1	28.9	251.4
s)	1	2	<1	<1	<1	<1	5	7	4	1	1	3	28
Mulegé, B.C. 26°53′N 112°00′W													
(°C)	14.0	16.0	17.8	20.1	22.9	27.2	30.5	30.4	29.0	24.6	19.5	14.9	22.2
)	2.6	3.4	0.1	0.2	0.1	0.0	6.1	16.8	40.4	5.4	6.8	19.2	101.1
s)	<1	<1	<1	<1	<1	0	<1	2	1	<1	<1	2	5
Topolobampo, Sin. 25°36′N 109°03′W													
(°C)	18.6	19.7	20.1	22.2	25.0	29.1	29.8	29.7	29.7	27.8	24.0	19.7	24.6
)	6.4	6.6	6.4	0.0	1.8	5.3	39.9	100.6	55.9	73.7	7.0	55.3	358.9
)	<1	<1	1	0	<1	<1	4	4	4	3	<1	4	24
La Paz, B.C. 24°10′N 110°18′W													
(°C)	18.4	18.9	21.2	23.2	25.6	27.0	30.2	30.1	28.9	27.1	23.5	20.5	24.6
max. (°C)	21.4	22.5	25.2	27.6	30.6	32.0	34.3	33.3	31.9	30.7	26.6	23.3	28.3
min. (°C)	15.7	15.8	17.5	18.8	21.2	22.7	27.0	27.1	26.4	23.9	20.6	17.8	21.2
	3.2	11.4	0.8	0.2	0.0	0.2	6.3	41.7	51.9	9.6	13.4	34.5	173.0
)	<1	2	<1	<1	0	<1	1	3	4	1	1	4	16
Mazatlán, Sin. 23°11′N 106°25′W													
(°C)	19.4	19.3	20.2	21.9	24.2	26.7	27.6	27.8	27.6	26.9	23.9	21.3	23.9
max. (°C)	21.7	21.7	22.7	24.4	26.4	28.6	29.7	29.9	29.5	29.0	26.3	23.5	26.1
min. (°C)	16.6	16.5	17.1	18.7	21.2	24.5	25.1	24.9	25.0	24.4	21.2	18.3	21.1
	11.0	9.7	3.4	0.1	1.8	29.2	166.9	241.8	268.6	61.6	11.7	44.4	850.2
)	1	1	<1	<1	<1	4	14	15	14	4	1	4	61
Isla María Madre, Nay. 21°35′W 106°30′W													
(°C)	21.1	20.0	20.6	22.6	25.0	27.0	27.8	27.7	27.8	25.2	24.0	21.5	24.2
max. (°C)	26.1	25.7	26.6	28.9	31.0	32.5	32.7	32.8	32.8	31.2	28.8	26.4	29.6
min. (°C)	16.5	14.8	14.0	15.1	18.0	21.6	23.4	23.6	23.8	22.0	19.9	16.4	19.1
	10.8	20.0	0.5	0.0	0.1	37.5	89.1	118.3	210.0	75.1	28.0	77.6	667.6
	<1	3	<1	<1	<1	2	9	11	4	4	1	4	46
Cabo Corrientes, Jal. 20°24′N 105°43′W													
(°C)	23.2	22.9	22.7	23.9	25.4	26.7	28.1	27.9	27.5	27.8	26.1	23.8	25.5
	19.5	29.6	1.3	0.0	2.3	57.3	145.0	272.1	307.0	91.0	15.2	13.5	953.8
	1	1	<1	0	<1	9	12	14	15	6	1	2	61

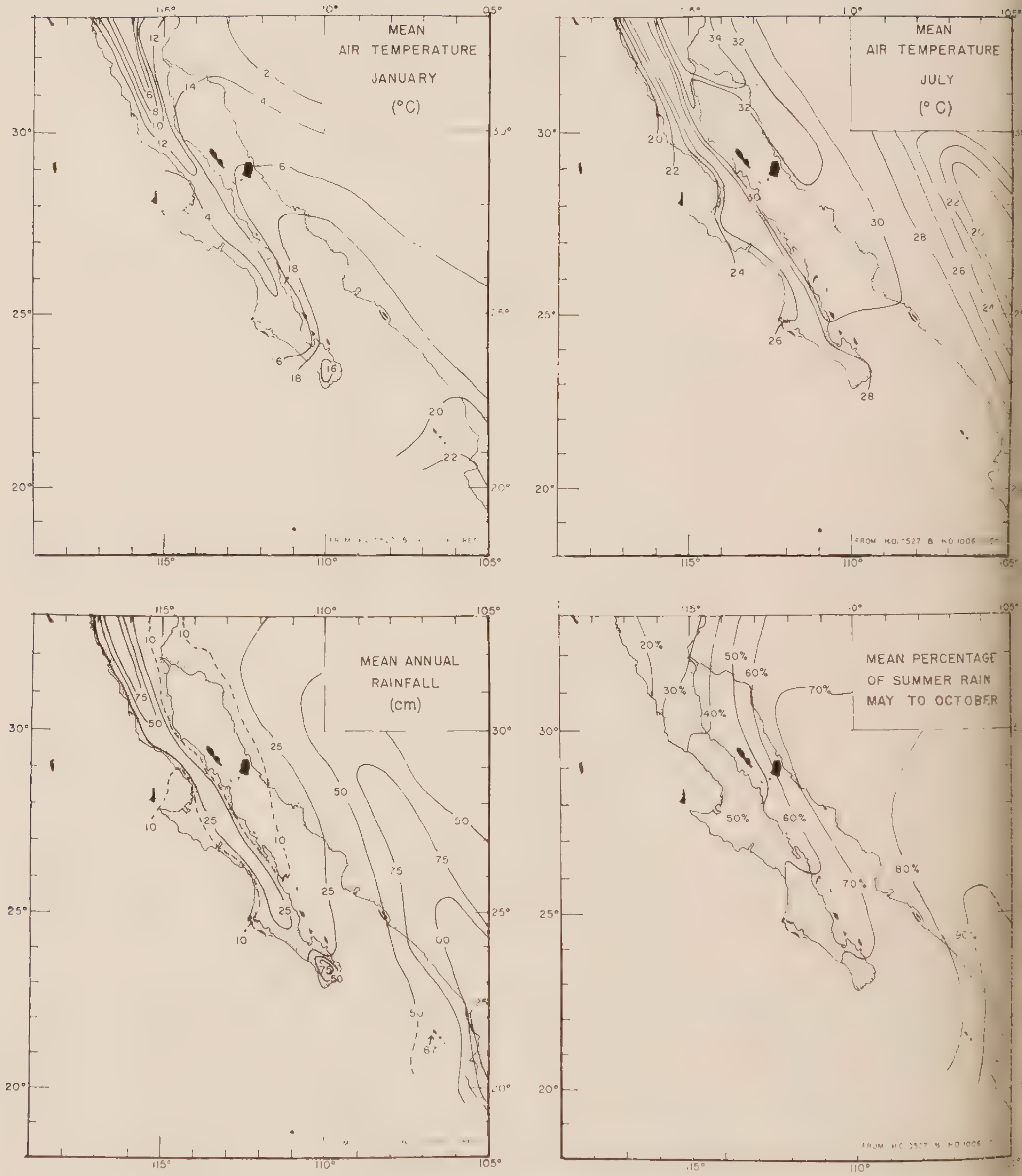
on San Luis, Rio Colorado, Sonora, is inland. It has been used here to illustrate conditions for the upper Gulf, for which no other available.

reflect those over the open Gulf. To esti- evaporation from the sea surface, an equa- the type

$$E = K\Delta e W$$

uently applied (Sverdrup, 1951). Here E is ation (cm/day), Δe is the vapor pressure ce between the sea surface and the air it (in millibars), and W is the wind speed). The proportionality factor K depends oth the height of observation and the wind for a height of 10 m and wind speeds be- 4 m/sec and 8 m/sec, its magnitude is Roden, 1959). The above equation is valid hen the stratification of the air is neutral, and when horizontal moisture gradients can be neglected. It is obviously not applicable in the coastal regions, where large horizontal humidity gradients occur, nor in the northern third of the Gulf where advection of dry desert air is considerable. For the southern two-thirds of the Gulf, the mean annual vapor pressure difference, when determined from sea and air temperature entries in the ship's meteorological journals, is about 8 millibars. With a mean annual wind speed of about 4 m/sec, the evaporation rate is estimated from equation (1) as 128 cm/year. This value is only 60 per cent of the pan evaporation at coastal stations. Inasmuch as neither method is very accurate, the discrepancy is not surprising.

Winds and hurricanes.—Winds in the Gulf of



MEAN AIR TEMPERATURE JANUARY (°C)

MEAN AIR TEMPERATURE JULY (° C)

MEAN ANNUAL RAINFALL (cm)

MEAN PERCENTAGE OF SUMMER RAIN MAY TO OCTOBER

FIG. 2.—Mean air temperature and mean precipitation in the Gulf of California and adjacent regions (after Page, 1930; and Ward and Brooks, 1936).

California are extremely variable. Near the coast, the land and sea breeze system prevails and the diurnal wind changes are usually larger than the annual ones (Table III). The sea breeze reaches its highest speeds, 5 m/sec to 7 m/sec, in the early afternoon and calms down after sunset. The land breeze is very much weaker and rarely a tains speeds in excess of 2 m/sec. Near th mountainous coast of Baja California, mounta and valley winds may locally predominate. I the more offshore regions of the Gulf, northwest erly winds prevail from November to May, a

TABLE III. MEAN MONTHLY AND MEAN MONTHLY MAXIMUM WIND SPEED AT FIRST ORDER METEOROLOGICAL STATIONS (After Servicio Meteorológico Mexicano, 1928–1941)

	I	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	*X*	*XI*	*XII*	*Mean*	*Years of Record*
							Mean wind speed (m/sec).							
aymas	5.2	5.9	6.2	6.7	5.2	4.6	3.9	3.5	5.4	5.6	5.6	5.3	5.3	10
Paz	2.5	2.2	2.3	2.4	2.0	2.4	2.0	2.0	1.6	1.9	2.3	2.2	2.2	6
zatlán	6.0	6.1	5.9	5.6	4.9	5.0	4.4	4.7	5.0	5.2	4.5	5.2	5.2	12
María Madre	2.3	2.7	2.8	2.7	2.8	2.6	2.0	2.1	2.3	2.2	1.9	2.2	2.4	3
							Mean maximum wind speed (m/sec).							
ymas	22.5	21.3	21.8	22.0	18.2	17.6	23.7	29.5	28.4	20.2	21.3	23.2	22.5	10
Paz	12.8	11.7	11.5	12.4	11.4	10.8	13.0	13.9	20.7	10.4	11.6	11.4	12.6	6
zatlán	15.8	17.3	15.5	15.3	15.4	17.8	22.6	24.6	28.8	18.1	13.8	16.1	18.4	12
María Madre	8.1	9.6	11.0	10.4	10.3	16.4	8.0	15.9	14.5	14.3	8.1	9.5	11.3	3

easterly ones during the rest of the year. erate northwest gales that last two or three at a time are frequently experienced in the Gulf between December and February. winds are particularly strong in Ballenas nel between the montainous Baja California and the equally high island of Angel de la da; they may on occasion raise such a sea that navigation becomes impossible Hydrographic Office, 1951). During summer, and hot desert winds are encountered fre- ly in the northern third of the Gulf. In the ern part of the Gulf, violent storms of rela- short duration, called *chubascos*, occur dur- he rainy season—from June to October. gales may last from two to four days, and blow from any quarter with speeds ranging en 12 m/sec and 19 m/sec (Beaufort, 6–8). ricanes may strike the coastal areas of the f California any time between late May and November. They are, however, much more common in September and October than during any other time of year. These hurricanes originate off the southern coast of Mexico or Central America, and proceed toward the west or northwest with speeds averaging between 180 and 360 nautical miles per day (Fig. 3). Upon reaching Cabo Corrientes, they may continue on a westward course (May to August), or they may curve to the north or northeast, either crossing the southern part of Baja California, or proceeding directly into the Gulf. Most hurricanes are dissipated before they reach the islands of Tiburón and Angel de la Guarda. In Table IV are shown pertinent hurricane data for recent years. It is seen that maximum wind speeds of 77 m/sec (150 kn) may be expected, and that the atmospheric pressure at the surface may drop to 958 millibars. Heavy loss of life and damage to ships may occur, as is amply illustrated by the October 1959 hurricane, which claimed about 1,000 lives and sank seven ships.

TABLE IV. RECENT HURRICANES AFFECTING THE GULF OF CALIFORNIA AND VICINITY (After U.S. Weather Bureau, 1954–1961)

Date	*First Reported*	*Coastline Crossed*	*Highest Observed Wind Speed*	*Lowest Atmos. Press.*	*Place of Dissipation*	*Remarks*
12–17 Jul.	14°N 95°W	Near Bahía Ballenas	39 m/s	991 mb	near Isla Tiburón	—
15–16 Oct.	16°N 104°W	north of Manzanillo	33 m/s	999 mb	north of Manzanillo	—
1–5 Oct.	18°N 118°W	Bahía Magdalena	46 m/s	996 mb	south of Guaymas	No hurricane affected the Gulf. Ship damage in Bahía Magdalena.
17–20 Oct.	13°N 103°W	none	41 m/s	986 mb	south of Mazatlán	—
20–21 Oct.	16°N 113°W	near Mazatlán	67 m/s	959 mb	near Mazatlán	Extensive damage to ships and structures in Mazatlán area.
29 Sept.–4 Oct.	16°N 100°W	tip of Baja California	46 m/s	960 mb	north of Guaymas	Town of San José del Cabo, Baja California virtually wiped out.
3–11 Sept.	13°N 93°W	Baja California	39 m/s	987 mb	31°N 116°W	—
22–27 Oct.	13°N 96°W	near Manzanillo	77 m/s	958 mb	northeast of Manzanillo	1,000 lives lost in Manzanillo Minatitlán, and nearby communities. Seven ships sunk.
21–23 Oct.	18°N 104°W	north of Mazatlán	32 m/s	989 mb	north of Mazatlán	—

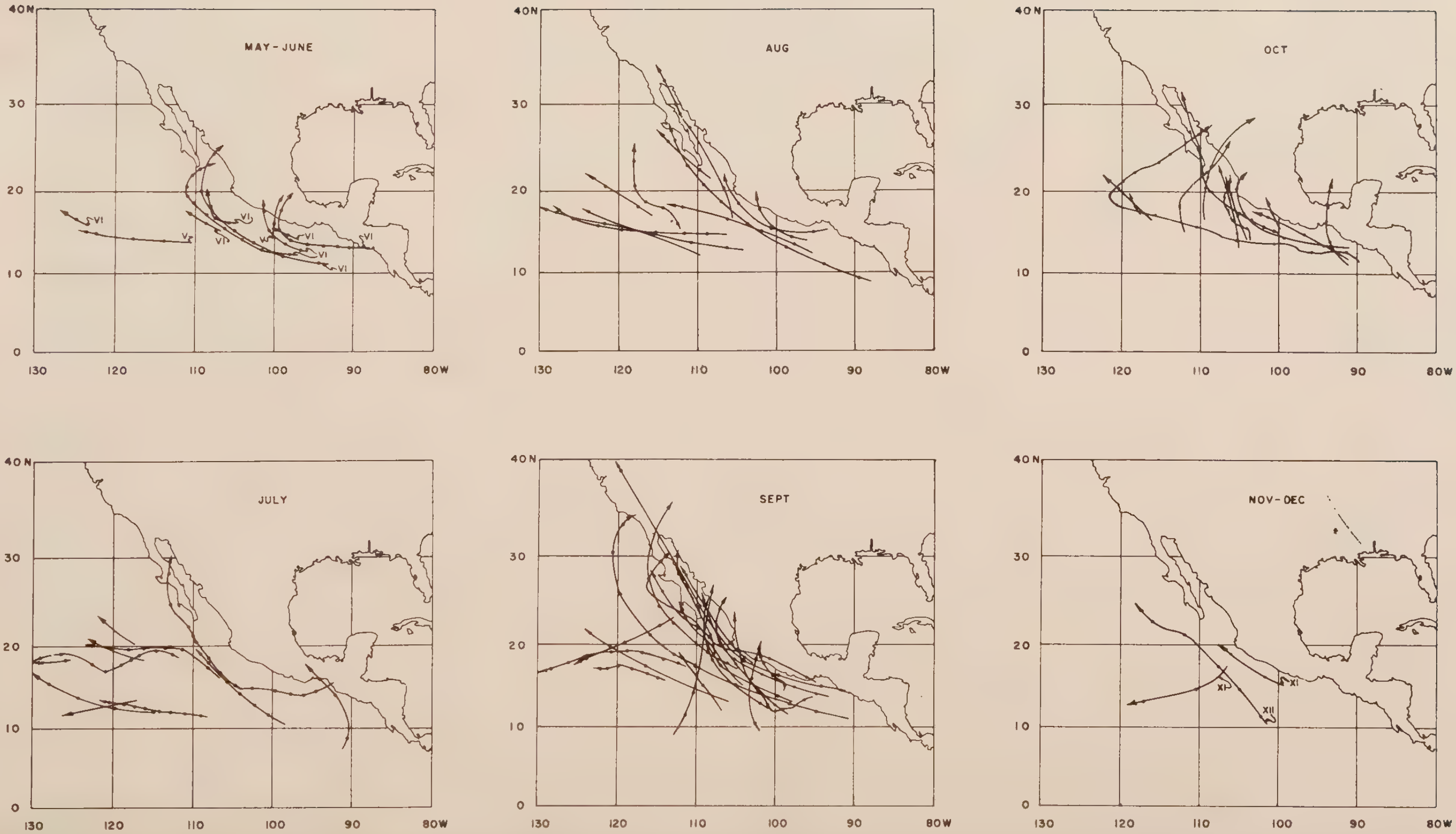


FIG. 3.—Paths of hurricanes in the northeastern Pacific. Dots represent positions for successive days (after Meteorological Office, London, 1956).

DISCHARGE AND CHEMICAL COMPOSITION OF RIVERS

The chief source of stream-borne sediments, at ast until the Hoover Dam was completed in 35, was the Colorado River; it is estimated that is river contributed about 50 per cent of the tal amount of sediment brought annually into e Gulf (Byrne and Emery, 1960). The mean nual discharge of the Colorado River at Yuma, izona, was about 600 m^3/sec prior to the con- uction of the Hoover Dam (U.S. Geological rvey, 1954); since then it has decreased to out 120 m^3/sec. The year-to-year variation of e discharge is large, and so is the seasonal varia- n. During the recent five-year period 1955–59, the discharge ranged from a minimum of 11 /sec in October 1956 to a maximum of 260 /sec in January 1958. Very little water is likely reach the Gulf in the summer and early fall onths.

The chemical composition of the Colorado ver at Yuma is given in Table V. The con- ntrations are expressed in equivalents per llion of cations and anions, except for silica d boron which may be present in a colloidal te and which are expressed in parts per million. is seen that the most abundant ions are sulfate, sodium, and calcium, followed by bicarbonate, chloride, and magnesium. The average annual concentrations given in Table V may differ by a factor of two for any particular month.

Along the southeastern coast, several large rivers enter the Gulf, the most important ones being, from north to south—Río Yaqui, Río Fuerte, Río Piaxtla, Río Presidio, Río Baluarte, and, particularly, Río Grande de Santiago. These rivers differ from the Colorado River by the fact that they carry more water during the summer and fall than during the winter and spring.

TIDES AND SEA LEVEL

Tide observations have been recorded from very few locations. In Table VI are shown eight of the more important tidal constituents at Bahia Magdalena on the west side of Baja California, Mazatlán near the Gulf entrance, and Guaymas in the central part of the Gulf. No station was available for the northern part. It is seen that the tides at Bahía Magdalena and Mazatlán are of a mixed type, with the semidiurnal components M_2 and S_2 being slightly larger than the diurnal components K_1 and O_1. At Guaymas, however, the diurnal components dominate over the semidiurnal ones. The composite tidal range

TABLE V. CHEMICAL ANALYSIS OF COLORADO RIVER WATER AT YUMA, ARIZONA

Values Represent Averages of Daily Observations Made from October 1956 to September 1957
(After U.S. Geological Survey Water-Supply Paper 1524 (1960)

	Mean	*Monthly Range*	*Unit*
SiO_2[1]	13	8–17	parts per million
Ca	5.49	5.09–6.69	equivalents per million
Mg	2.80	2.38–3.37	equivalents per million
Na	5.70	4.61–6.74	equivalents per million
K	0.14	0.12–0.15	equivalents per million
HCO_3	2.87	2.75–3.08	equivalents per million
SO_4	7.62	6.60–8.29	equivalents per million
Cl	3.58	2.99–4.17	equivalents per million
F	0.02	0.02–0.03	equivalents per million
NO_3	0.02	0.00–0.03	equivalents per million
B	0.24	0.20–0.24	parts per million
dissolved solids[2]	889	791–1,000	parts per million
per cent sodium[3]	40	32–43	per cent
sodium absorption ratio	2.8	2.1–3.2	—
specific conductance	1,340	1,270–1,470	micro-ohms at 25°C
pH	—	7.7–8.2	—
discharge	28	11–60	m^3/sec

Colloidal state.

Residues after evaporation at 180°C.

Calculated from $\frac{100\ Na}{Na+K+Ca+Mg}$.

TABLE VI. TIDAL CONSTANTS IN AND OUTSIDE GULF OF CALIFORNIA

(H) Refers to Amplitude of each component; (K) to the epoch
(After U.S. Coast and Geodetic Survey Measurements *in*: Hydrographic Department, London, 1961)

Component	K_1	O_1	P_1	Q_1	M_2	S_2	N_2	K_2	*Record Length*
Period (hours)	*23.93*	*25.82*	*24.07*	*26.87*	*12.42*	*12.00*	*12.66*	*11.97*	
Bahía Magdalena, B.C. 24°38′N 112°09′W (outside Gulf)									
H (cm)	24	17	8	—	49	31	12	8	30 days
K (deg)	071	077	071	—	244	253	246	253	
Mazatlán, Sin. 23°11′N 106°27′W (Gulf entrance)									
H (cm)	20	14	8	—	33	23	7	7	369 days
K (deg)	072	075	069	—	265	254	254	248	
Guaymas, Son. 27°55′N 110°54′W (central Gulf)									
H (cm)	27	19	9	4	14	11	4	3	221 days
K (deg)	071	058	070	049	295	276	305	271	

(Fig. 4) increases gradually from the Gulf entrance to Isla Tiburón, and then rapidly to the mouth of the Colorado. At the latter, the spring tidal range is about 10 m, the average range 7 m, and the neap range 2 m. The tidal wave continues into the Colorado River in the form of a tidal bore. Marigram records of the bore at a station about 25 km upstream (Valenzuela, personal communication) show that the front of the bore is an almost vertical wall of water, 1.5 m–3 m high, and that after the passage of the front, the water level decreases gradually with time, until the front of the next bore appears, almost 12 hours later.

The time of high or low water gets progressively later up the Gulf, the time difference between the Gulf entrance and the vicinity of the Colorado River being approximately 5.5 hours for high water and 6 hours for low water. Thus one observes the interesting feature that when there is low water at one end of the Gulf, there is high water at the other. Whether the tidal wave is a progressive or a standing one cannot be decided from the meager data available (Roden and Groves, 1959).

Tidal currents in the narrows between the islands and the coast, and in the vicinity of the delta of the Colorado River are strong, sometimes causing heavy rip tides. Strong tidal currents may also be expected in narrow passages connecting semienclosed lagoons with the open Gulf. The speed of these currents is variable, depending upon the stage of the moon and the prevailing winds. Velocities up to 3 m/sec (6 kn) at full ar change of the moon have been reported locall (U.S. Hydrographic Office, 1951).

Sea-level records from tide gage stations in th Gulf (Instituto de Geofísica, Univ. Nac. Aut Mexico D.F., unpublished) show that the ampl tude of the mean annual oscillation increases fro 13 cm at Mazatlán to 17 cm at Guaymas (Tab VII). The lowest sea levels occur from Februar to April and the highest from July to Septembe The amplitude of the annual sea-level change du to heating and salinity effects in the upper 500 is about 16 cm, which suggests that most of th observed annual sea-level changes are due changes in heat and salt content. A similar resu was obtained by Pattullo, Munk, Revelle, ar Strong (1955). The nonseasonal sea-level oscilla tions in the Gulf of California and adjacer regions are shown in Figure 5. The seasonal varia tion was eliminated by taking differences betwee the monthly means and the long-term means fo the respective months. Although the details the resulting anomaly records vary, sever common features stand out—(a) the mean ampl tude of the nonseasonal sea-level oscillatic appears to be close to 7 cm, or to about half th mean annual oscillation; (b) sea-level oscillatio in the Gulf are of the same type as elsewhe along the southern coast of Mexico; (c) the ave age duration of the sea-level anomalies appears be of the order of several months. A spectr analysis of the nonseasonal sea-level variatio

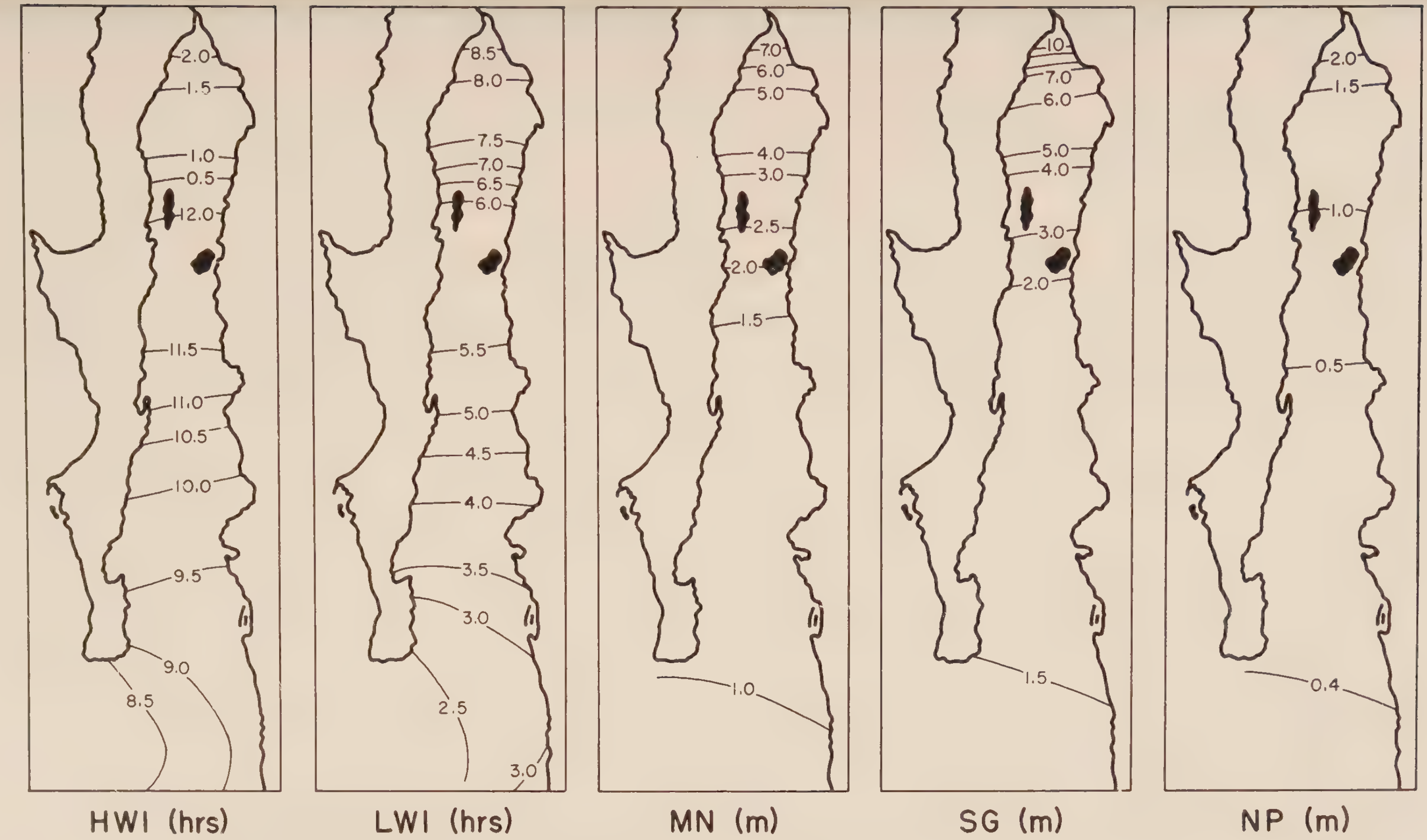


FIG. 4.—Tides in the Gulf of California. HWI and LWI refer to high and low water interval in hours. MN, SG, and NP denote the mean, spring, and neap tidal ranges in meters.

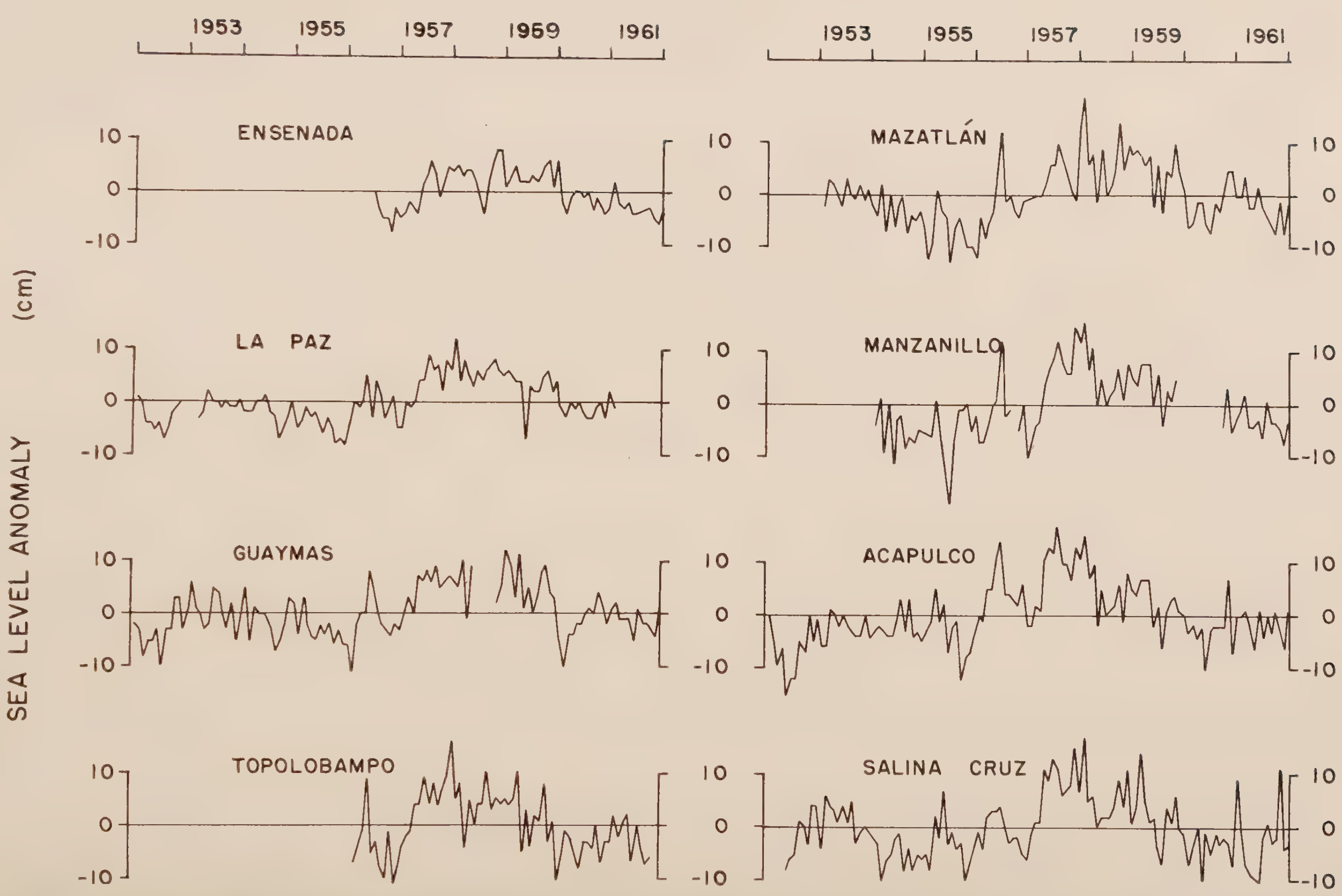


FIG. 5.—Sea level anomalies from the long-term monthly means along the Pacific coast of Mexico. The stations La Paz, Guaymas, Topolobampo, and Mazatlán are in the Gulf of California.

TABLE VII. SEA LEVEL AND SEA SURFACE TEMPERATURE OBSERVATIONS AT TIDE GAGE STATIONS IN THE GULF OF CALIFORNIA

	I	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	*X*	*XI*	*XII*	*Annual Record*			
													Mean	*Range*	*Length*	*Source*
							Sea level (cm)									
Guaymas	−14.1	−14.7	−14.0	−9.3	−0.8	+12.6	+18.8	+17.6	+18.3	+6.8	−9.5	−11.7	0	33.5	11	IG-UNAM
Topolobampo	−9.7	−13.3	−14.9	−12.7	−2.8	+11.4	+16.6	+15.4	+18.2	+7.2	−4.9	−10.5	0	33.1	6	IG-UNAM
La Paz	−6.9	−8.9	−11.4	−10.5	−7.5	−1.9	+6.0	+11.5	+14.4	+11.0	+6.0	−1.7	0	25.8	11	IG-UNAM
Mazatlán	−4.7	−9.3	−12.2	−11.1	−3.4	+7.0	+13.8	+12.7	+12.9	+5.0	−5.1	−5.6	0	25.1	10	IG-UNAM
Isla Socorro[1]	−0.9	−2.2	−0.2	+0.4	+2.4	+1.8	−1.5	−1.4	+2.5	+1.0	−0.5	−1.4	0	4.7	1	IG-UNAM
							Mean sea surface temperature (°C)									
Puerto Peñasco	14.9	15.8	17.8	20.6	23.8	26.3	29.7	31.2	31.0	28.4	22.0	17.1	23.2	16.3	4	USCGS
Bahía de los Angeles	16.0	15.8	15.6	17.1	18.0	21.0	25.1	27.1	25.1	23.6	19.0	16.0	20.0	11.5	1	SIO
Guaymas	17.4	18.3	19.2	22.3	25.2	29.5	31.6	31.6	31.2	28.1	22.7	18.2	24.6	14.2	8	USCGS
Topolobampo	19.0	20.0	21.0	23.6	26.3	29.7	31.1	31.5	31.3	28.9	23.1	19.5	25.4	12.5	6	USCGS
La Paz	20.3	20.3	21.6	22.7	24.3	25.2	27.5	29.1	29.7	28.2	25.2	21.8	24.7	9.4	11	USCGS
Mazatlán	22.2	21.1	21.3	22.5	24.9	28.2	29.6	30.0	30.1	28.8	25.2	22.9	25.6	9.0	9	USCGS
Cabo San Lucas	20.8	20.5	—	20.6	23.1	23.6	25.9	28.2	29.0	—	26.2	24.4	24.2	(8.5)	1	SIO
Isla Socorro[1]	24.6	24.3	25.0	—	—	—	28.3	27.3	28.6	—	—	—	—	(4.3)	1	USCGS
							Mean minimum sea surface temperature (°C)									
Puerto Peñasco	12.8	14.4	15.8	17.8	21.0	23.0	27.5	30.0	29.2	25.8	19.2	13.8	20.9	17.2	4	USCGS
Bahía de los Angeles	—	—	—	15.8	16.0	18.6	21.8	22.5	22.5	19.4	17.5	15.0	—	—	1	SIO
Guaymas	15.6	15.9	15.3	18.1	19.8	26.4	29.1	27.7	28.9	25.8	19.9	14.3	21.4	14.8	3	USCGS
La Paz	17.7	17.3	19.3	20.4	21.9	21.9	24.2	27.0	27.3	26.4	23.1	19.8	22.2	10.0	6	USCGS
Mazatlán	18.5	18.3	18.2	19.1	20.8	24.9	28.2	28.8	26.7	26.1	22.2	17.8	22.5	10.0	3	USCGS
							Mean maximum sea surface temperature (°C)									
Puerto Peñasco	17.6	17.8	20.2	23.3	26.0	28.9	32.0	32.2	32.2	30.6	25.7	19.7	25.5	14.6	4	USCGS
Bahía de los Angeles	16.6	16.2	16.0	19.1	19.9	24.0	27.0	28.5	27.6	25.0	23.0	18.0	21.7	12.5	1	SIO
Guaymas	22.2	20.3	21.7	23.3	29.2	32.8	33.0	33.8	33.9	31.5	27.4	22.7	27.7	13.6	3	USCGS
La Paz	21.5	21.7	24.3	25.7	27.2	27.7	29.8	31.3	31.3	30.3	27.7	24.3	26.9	9.8	6	USCGS
Mazatlán	22.7	22.7	23.8	24.9	26.0	30.0	30.8	31.1	31.3	29.4	27.8	23.8	27.0	8.6	3	USCGS

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[1] Isla Socorro is outside the Gulf and has been added for comparison.

showed that most of them are related to variations in temperature at low frequencies, and that there is very little relation between sea level and atmospheric pressure relations (Roden, 1960).

SURFACE CURRENTS

Direct current measurements in the interior regions of the Gulf are nonexistent. The few currents determined from the drift of ships indicate that the flow is predominantly southeasterly in winter and spring and northwesterly in summer and fall (Fig. 6). North of Isla Tiburón, and in the narrows between the islands and the coast, tidal currents predominate. These may reach speeds between 1 m/sec and 3 m/sec, and they are frequently accompanied by strong rips and impressive eddies (U.S. Hydrographic Office, 1951). Across the Gulf entrance, between Cabo San Lucas and Cabo Corrientes, the surface currents are variable (Table VIII). Southeasterly set with speeds ranging between 10 cm/sec and 15 cm/sec is commonly observed from February to May. Between June and September, the set is generally toward the northwest with maximum speeds of about 10 cm/sec. During the remaining months of the year, the currents are weak and set mostly toward a westerly or southwesterly direction.

SOME HYDRODYNAMIC ASPECTS OF CURRENTS

We shall here consider only a linear and stationary model. Assuming that the total pressure, p, is equal to the sum of the hydrostatic pressure, p_o, and the atmospheric pressure, p_a, the equations of motion and continuity take the following form

$$(1)\qquad \mathbf{k}\times \mathbf{V}_H = -\frac{\alpha}{f}\nabla_H p_o - \frac{\alpha}{f}\nabla_H p_a + \frac{\alpha}{f}\frac{\delta \boldsymbol{\tau}_H}{\delta z}$$

$$(2)\qquad 0 = -\alpha\frac{\partial p}{\partial z} - g$$

$$(3)\qquad \frac{\partial \rho w}{\partial z} = -\nabla_H \cdot \rho \mathbf{V}_H .$$

Here $\mathbf{v}_H$ is the horizontal (vector) velocity, w is the vertical velocity, $\boldsymbol{\tau}_H$ is the horizontal (vector) stress due to vertical shear, $\nabla_H p_o$ is the horizontal (hydrostatic) pressure gradient in the ocean, $\nabla_H p_a$ is the horizontal pressure gradient in the atmosphere, f is the Coriolis parameter, g is gravity, ρ is density, $\alpha = 1/\rho$ is the specific volume, and $\mathbf{k}$ is a unit vector. The first term of the righ hand side of the equation (1) denotes the geo strophic part of the current, the second term, th part due to the atmospheric pressure gradient and the third term, the part due to the vertica gradient of the stress. The geostrophic term ca be evaluated from temperature and salinity ob servations at different depths. The term contain ing the atmospheric pressure can be obtained from the weather map. The evaluation of th vertical gradient of stress, however, presents som difficulties. At the sea surface the stress mus equal that of the wind. A rough estimate of th latter can be obtained from the well known ex pression $\tau = k'\rho_a W^2$ (Sverdrup, Johnson, an Fleming, 1946) where ρ_a is the density of ai (1.2×10^{-3} g/cm^3) and W is the wind speed nea the sea surface (cm/sec). The proportionalit factor is $k' = 2.6\times 10^{-3}$, approximately. At the se surface, the gradient $\partial\bar{\tau}_H/\partial z$ can be approximated by $-\boldsymbol{\tau}_{Ho}/H$ where H (to be taken as a negativ value) is the depth to the bottom of the uppe mixed layer, where the wind stress is supposed t vanish (Yoshida, 1955).

The magnitude of the terms on the right han side of equation (1) is as follows *at the surface* *the Gulf*

February: $-\frac{\alpha}{f}\nabla_H p_0 = -4$ cm/sec;

$-\frac{\alpha}{f}\nabla_H p_a = -1$ cm/sec;

$\frac{\alpha}{f}\frac{\partial\bar{\tau}_{Ho}}{\partial z} = -5$ cm/sec.

August: $-\frac{\alpha}{f}\nabla_H p_0 = +13$ cm/sec;

$-\frac{\alpha}{f}\nabla_H p_a = +2$ cm/sec;

$\frac{\alpha}{f}\frac{\partial\bar{\tau}_{H0}}{\partial z} = +6$ cm/sec.

Here, the positive sign is taken to denote inflow and the negative one, outflow. The net surfac current across the Gulf entrance is thus -1 cm/sec in February and $+21$ cm/sec in August The above values are in reasonable agreemen with the observed ship drifts (U.S. Hydrographi Office, 1947). It is of interest to note that th contribution to the net current of the term con taining the horizontal gradient of atmospheri

TABLE VIII. SPEED AND DIRECTION OF SURFACE CURRENTS IN THE VICINITY OF THE GULF OF CALIFORNIA
(After U.S. Hydrographic Office, 1947)

	I	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	*X*	*XI*	*XII*	*Notes*
						18–19 N	104–105 W						
V (cm/sec)	12.8	12.5	15.3	2.1	5.5	13.2	11.3	9.8	4.6	2.1	7.6	12.4	Off Manzanillo
degrees	300	230	230	190	280	300	290	300	290	230	300	310	
						19–20 N	106–107 W						
V (cm/sec)	8.7	10.3	10.6	8.0	4.0	8.8	10.7	5.1	3.0	7.6	8.8	8.4	Off Cabo Corrientes
degrees	220	190	180	190	190	300	300	270	300	190	230	220	
						20–21 N	107–108 W						
V (cm/sec)	8.7	10.3	10.6	8.0	4.0	8.8	7.6	5.1	2.1	3.6	6.6	8.8	Entrance to Gulf of California
degrees	230	180	180	190	190	300	290	300	340	270	240	210	
						21–22 N	108–109 W						
V (cm/sec)	6.4	9.2	9.1	6.3	5.1	2.1	4.0	3.5	2.1	6.2	4.0	6.6	
degrees	230	160	180	160	160	190	310	340	020	300	250	230	
						22–23 N	110–111 W						
V (cm/sec)	4.0	10.7	12.4	15.0	11.3	5.5	4.0	4.6	4.0	6.3	7.5	4.0	Off Cabo San Lucas
degrees	230	170	150	160	170	180	230	280	250	240	270	210	
						23–24 N	111–112 W						
V (cm/sec)	5.1	9.8	14.3	17.0	15.4	10.3	4.0	2.1	3.6	4.6	7.5	2.6	
degrees	220	150	150	160	160	170	200	250	260	260	300	220	
						24–25 N	112–113 W						
V (cm/sec)	4.5	12.8	11.8	15.0	16.5	11.3	7.2	16.7	3.6	4.6	4.6	3.0	Off Bahía Magdalena
degrees	170	170	150	140	160	160	180	220	280	290	290	220	
						25–26 N	113–114 W						
V (cm/sec)	3.6	7.6	11.8	13.2	15.0	11.8	7.7	3.0	3.0	4.0	3.0	2.1	
degrees	180	160	180	150	160	140	170	180	230	290	300	240	

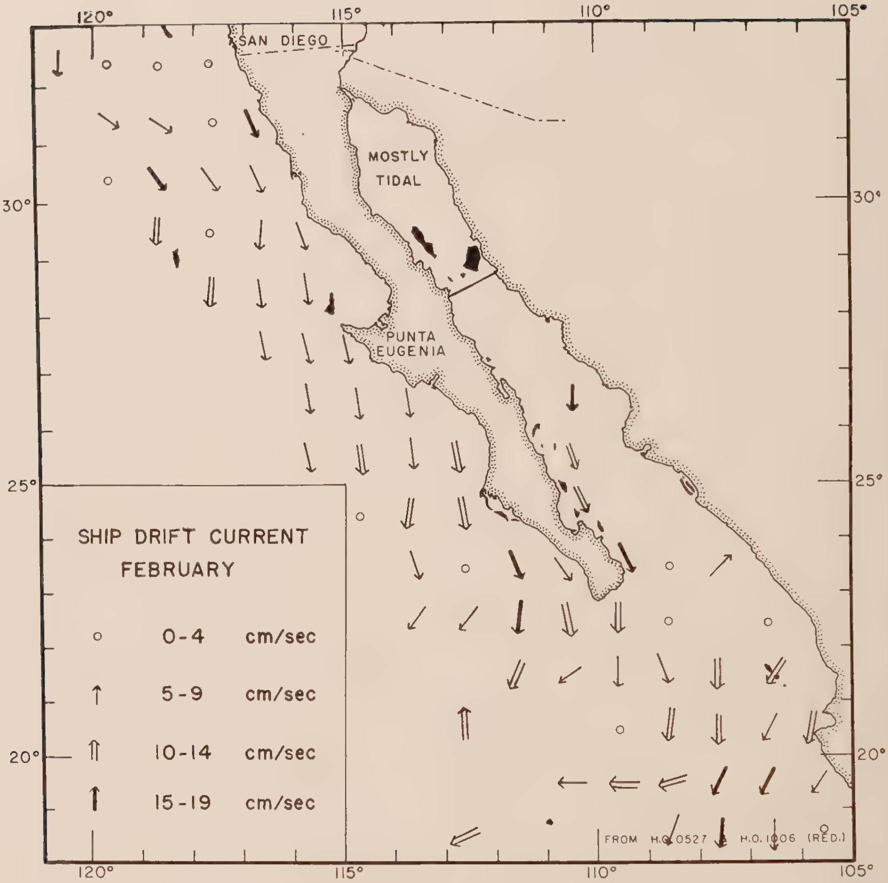


Fig. 6.—Ship drift currents in the Gulf of California a

pressure is not negligible in comparison to the other terms. At depths, where the geostrophic currents are weak, this term may be of considerable importance.

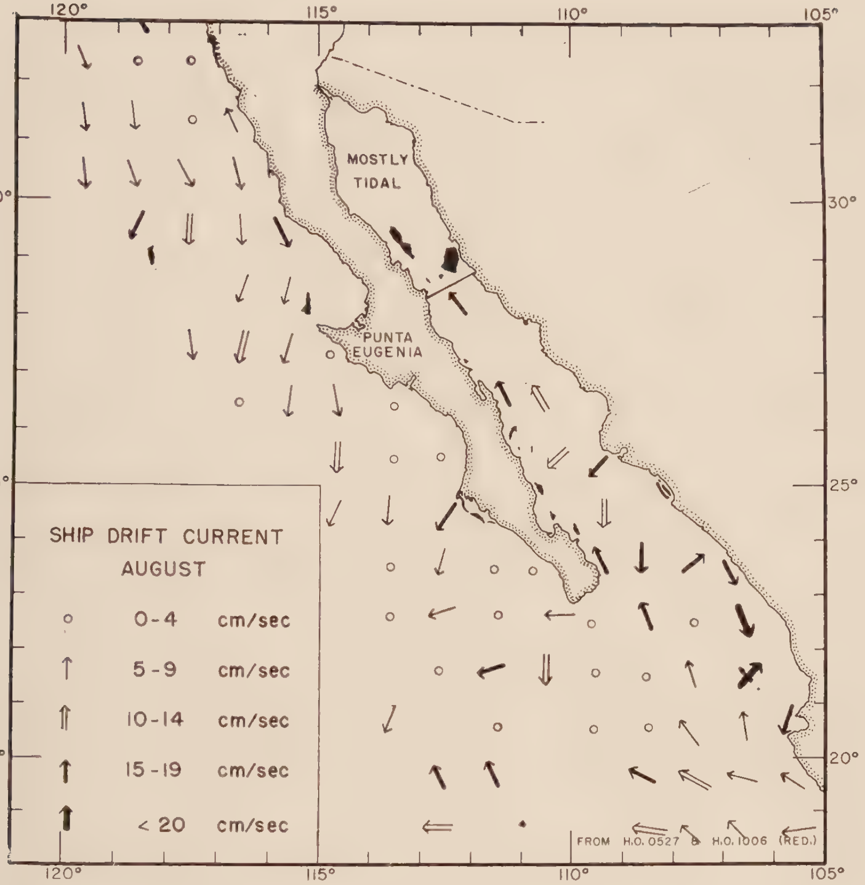
It is obvious that inflow and outflow must compensate each other closely in the Gulf of California; if this were not so, the sea-level changes in the Gulf would be unreasonably large. Whether compensation takes place by opposite flow at different levels, or by opposite flow along the shores of the Gulf, or both, cannot be decided with accuracy from the available data.

A rough estimate of the vertical velocity, w, can be obtained by integrating the equations of motion and continuity with respect to z and taking the integration limits between H, the depth where the wind stress is supposed to vanish (such the bottom of the upper mixed layer), and η, t sea surface. After some calculations, one obtai

$$(4)\quad W_H = \frac{\beta}{f^2\bar{\rho}}\left[H\frac{\partial pa}{\partial x} + \bar{\rho}hH\frac{\partial \eta}{\partial x} + \tau_{xo}\right] + \frac{\nabla_{H\times\tau_o}}{\bar{\rho}f}.$$

Here w_H is the vertical velocity at the bottom the upper mixed layer, H, here assumed consta $\bar{\rho}$ is the mean density of the upper mixed layer, the change of the Coriolis parameter with latitu τ_{x0}, the wind stress component toward the east the sea surface, and $\nabla_{H}\times\tau_o$ the vertical compon of the curl of the wind stress at the sea surface.

The terms on the right hand side of equati (4) can be roughly evaluated from a knowled



ent regions (after U.S. Hydrographic Office, 1947).

e atmospheric pressure and wind distribu- at the sea surface, and from hydrographic vations at different depths. Making use of ata collected by the February 1957 cruise he Gulf, the following results are obtained e central region (Section 127 G of Fig. 1)

t coast—

$$\frac{\beta}{\bar{\rho} f^2} H \frac{\partial p_a}{\partial x} = 0.5 \times 10^{-5} \text{ cm/sec;}$$

$$\beta/f^2 gH \frac{\partial \eta}{\partial x} = 1.8 \times 10^{-4} \text{ cm/sec}$$

$$\frac{\beta}{\bar{\rho} f^2} \tau_{xo} = 2.8 \times 10^{-5} \text{ cm/sec;}$$

$$\frac{\nabla_H \times \tau_o}{\bar{\rho} f} = 3.6 \times 10^{-3} \text{ cm/sec.}$$

West coast—

$$\frac{\beta}{\bar{\rho} f^2} H \frac{\partial p_a}{\partial x} = 1.3 \times 10^{-5} \text{ cm/sec;}$$

$$\frac{\beta}{f^2} gH \frac{\partial \eta}{\partial x} = -0.9 \times 10^{-4} \text{ cm/sec}$$

$$\frac{\beta}{\bar{\rho} f^2} \tau_{xo} = 2.2 \times 10^{-5} \text{ cm/sec;}$$

$$\frac{\nabla \times \tau}{f \bar{\rho}} = -2.7 \times 10^{-3} \text{ cm/sec.}$$

It is seen that the dominant term is that involving the vertical component of the curl of the wind stress; it is positive along the Mexican mainland coast and negative along the Baja California coast. Upwelling can therefore be expected to occur at the former and downwelling at the

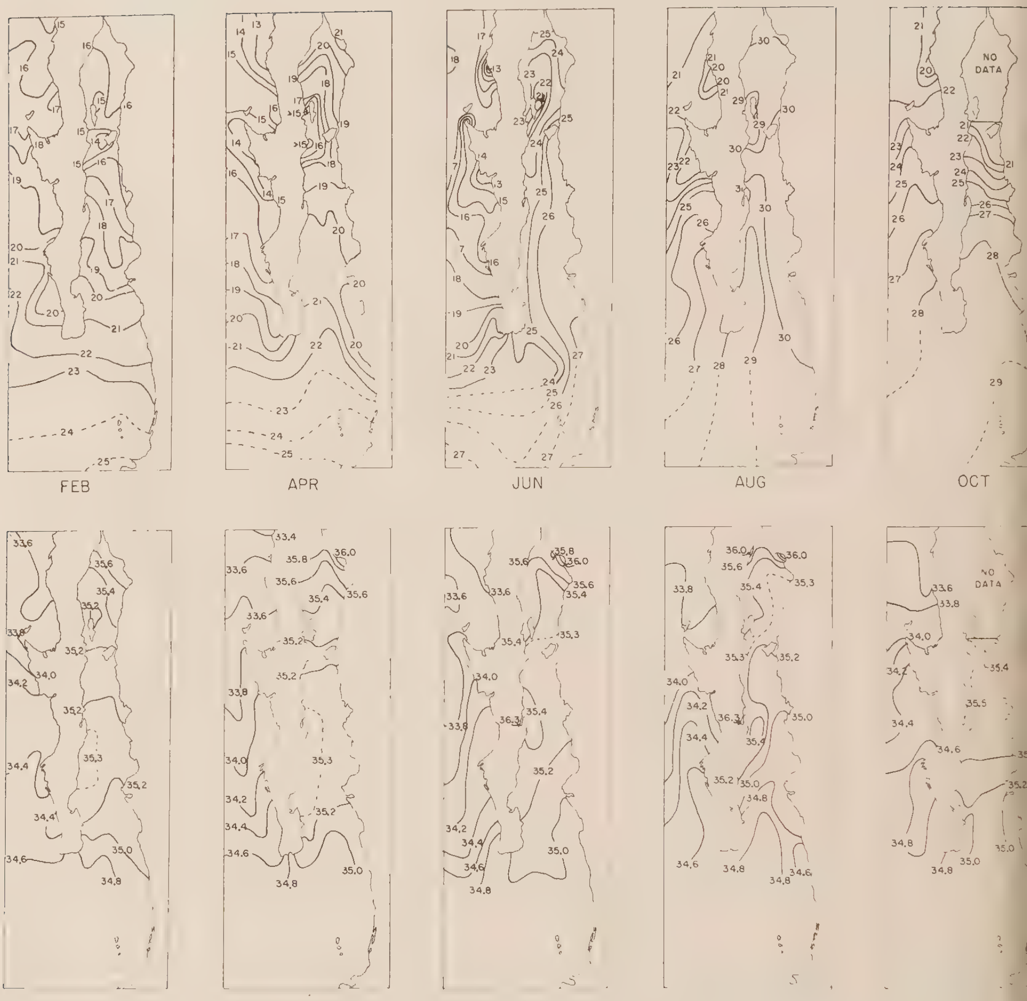


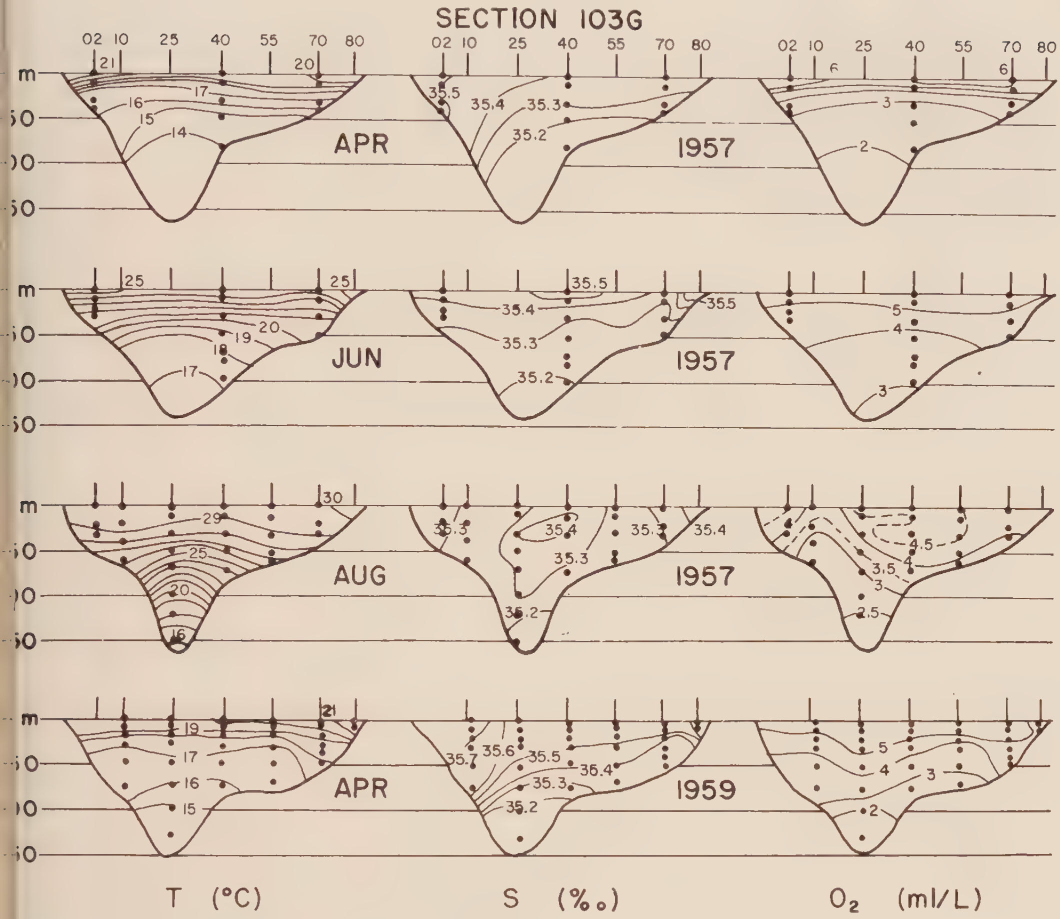
FIG. 7.—Temperature (top) and salinity (bottom) at a depth of 10 m. The dashed lines are extrapolations based on merchant ship observations.

latter. An inspection of the surface temperatures in Figure 7 shows that this is actually the case. The net upwelling speed along the east coast is about 3.8 × 10^{-3} cm/sec, or roughly 3.2 m per day.

DISTRIBUTION OF PROPERTIES

TEMPERATURE AND SALINITY IN SURFACE LAYERS

The distribution of temperature and salinity at the 10 m level is shown in Figure 7. This level, rather than the sea surface, was chosen in order to eliminate diurnal effects. Compared to tempe tures in the neighboring Pacific, those in the G are warmer from April to September and ab equal during the remaining months of the ye The annual range is large and increases from ab 9°C near Cabo Corrientes, to roughly 15°C n the mouth of the Colorado River. The low temperatures do not occur in the upper shal Gulf, but, instead, are found in the vicinity Isla Angel de la Guarda, where tidal mixing strong. The low temperatures along the east co



. 8.—Distribution of temperature, salinity, and dissolved oxygen in the upper Gulf (Section 103 G of Fig. 1).

l in lee of Isla Tiburón in winter, are related to welling, caused by the prevailing northwesterly nds. In summer, southeasterly winds lead to velling and cooler temperatures along the Baja ifornia coast.

alinities in the northern two-thirds of the Gulf ge mostly between 35.0°/oo and 35.8°/oo and 1°/oo–2°/oo higher than those at comparable tudes outside the Gulf. Salinities higher than /oo are only encountered locally in semien- ed and shallow bays in the northern region along the east coast of Baja California; the gest of these are Bahía Concepción, Bahía ír, and Bahía San Jorge. In the southern third the Gulf, between Cabo San Lucas, Cabo Corrientes, and the mainland, offshore salinities range mostly between 34.6°/oo and 35.0°/oo. In coastal waters the salinity may be considerably less than 34.6°/oo during the rainy season, June to October.

VERTICAL DISTRIBUTION OF PROPERTIES

Northern Gulf (*Fig. 8*).—This region, between the Colorado River and Isla Tiburón is characterized by large seasonal and year-to-year changes of temperature and salinity in the upper 150 m. During winter, the water is almost isothermal in the shallow northern part, judging from the few bathythermograph observations by the R/V *Alaska* (unpublished). During late

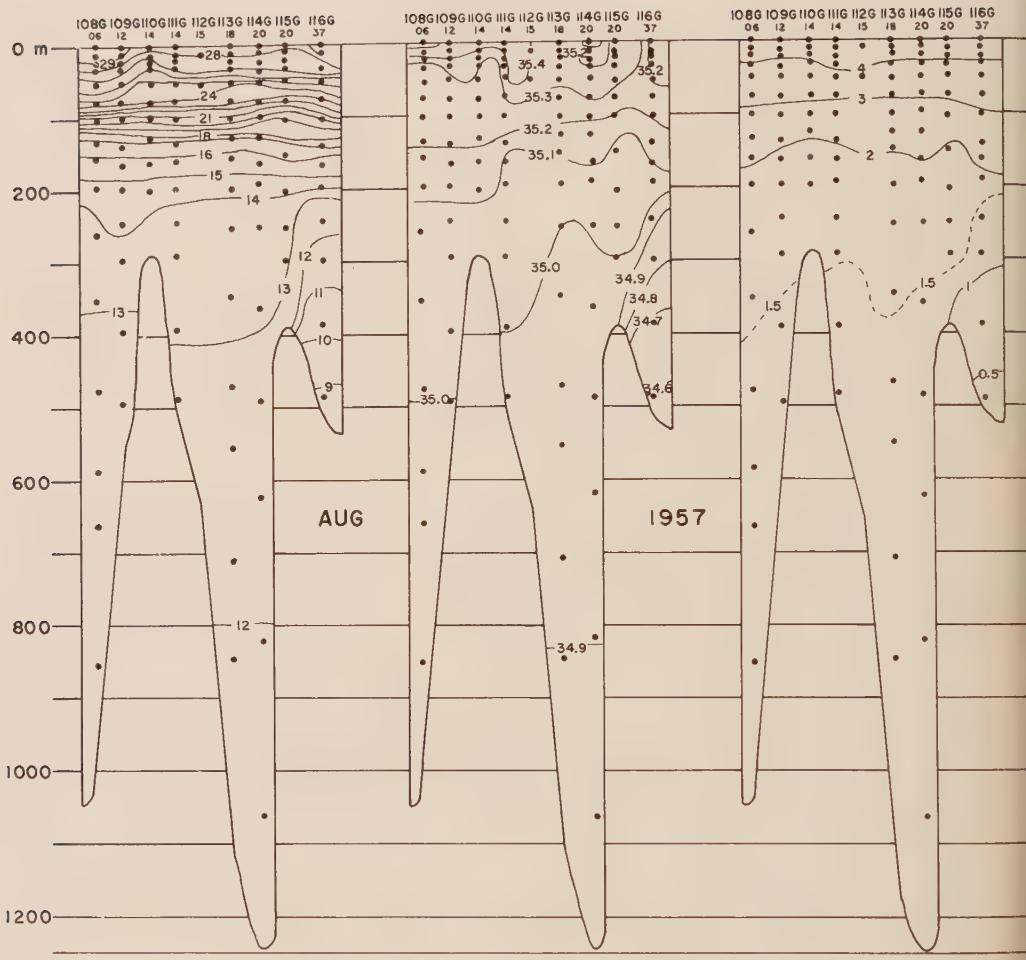
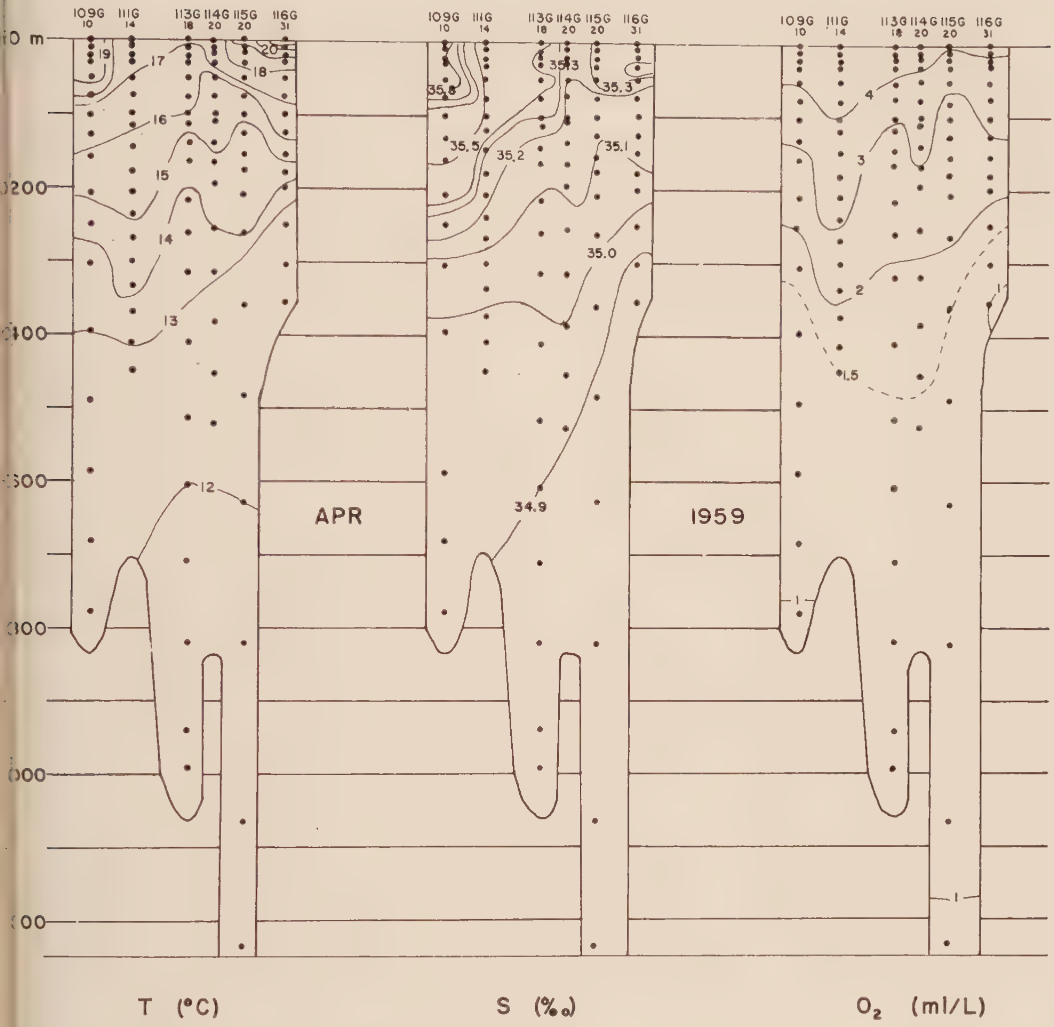


FIG. 9.—Distribution of temperature, salinity, and dissolv

summer, the thermocline is strong and the temperature difference between the surface and 150 m amounts to almost 14°C. In spring, salinities tend to be higher along the Baja California than along the Sonoran coast, whereas in summer the highest salinities appear in the more central parts of the Gulf. The amount of dissolved oxygen at the surface decreases from about 5.5 ml/L in April, to about 4.5 ml/L in August, the decrease being mostly due to the increase in temperature. At the bottom (150 m), however, there is a slight increase in dissolved oxygen content from spring to summer, despite a temperature increase and a strongly developed thermocline.

It is of interest to know whether winter cooli
can lead to convective overturn in the northe
part of the Gulf, and where, if at all, this is like
to occur. The requirement for the process to ta
place is that the surface density exceed the de
sity of the subsurface layers. Because the densi
increases with decreasing temperature and i
creasing salinity, and because the lowest tempe
tures and the highest salinities occur near t
coast, the most likely places for convective ove
turn are the coastal regions. The mean minimu
temperature in coastal regions is about 13



gen in Ballenas Channel (for location, see Fig. 1).

ble VII), whereas the salinities are generally
excess of 35.5‰. For a temperature of 13°C
l a salinity of 35.5‰, the density at the sur-
e is 1.02680 g cm^{-3}. The same density (*in situ*)
ound at a depth of about 100 m, where the
nperature is 14°C and the salinity is 35.2‰.
nvective overturn due to winter cooling can
refore be expected to reach to roughly 100 m
r the coast. In the more offshore parts of the
lf, surface temperatures do not drop much
ow 15°C, whereas the salinities average about
1‰. With these conditions, convection is in-
nificant.

Ballenas Channel (*Fig. 9*).—The Ballenas Channel, which lies between Isla Angel de la Guarda, Isla San Lorenzo, and Baja California, is completely isolated from the southern part of the Gulf by a submarine ridge connecting Isla Angel de la Guarda with Punta San Gabriel. The sill depth of this ridge is about 250 m. The topography of the channel is very irregular with maximum depths exceeding 1,500 m. The outstanding hydrographic features of the channel are the high temperatures, salinities, and oxygen concentrations at great depths. Compared to conditions elsewhere in the Gulf, the difference in tempera-

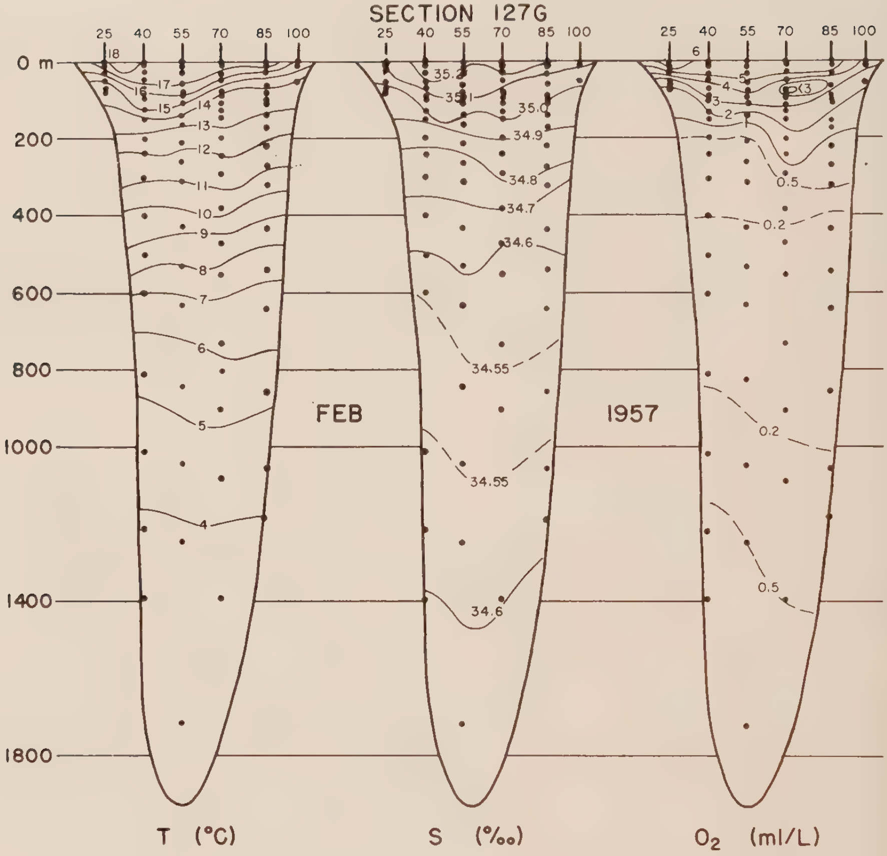
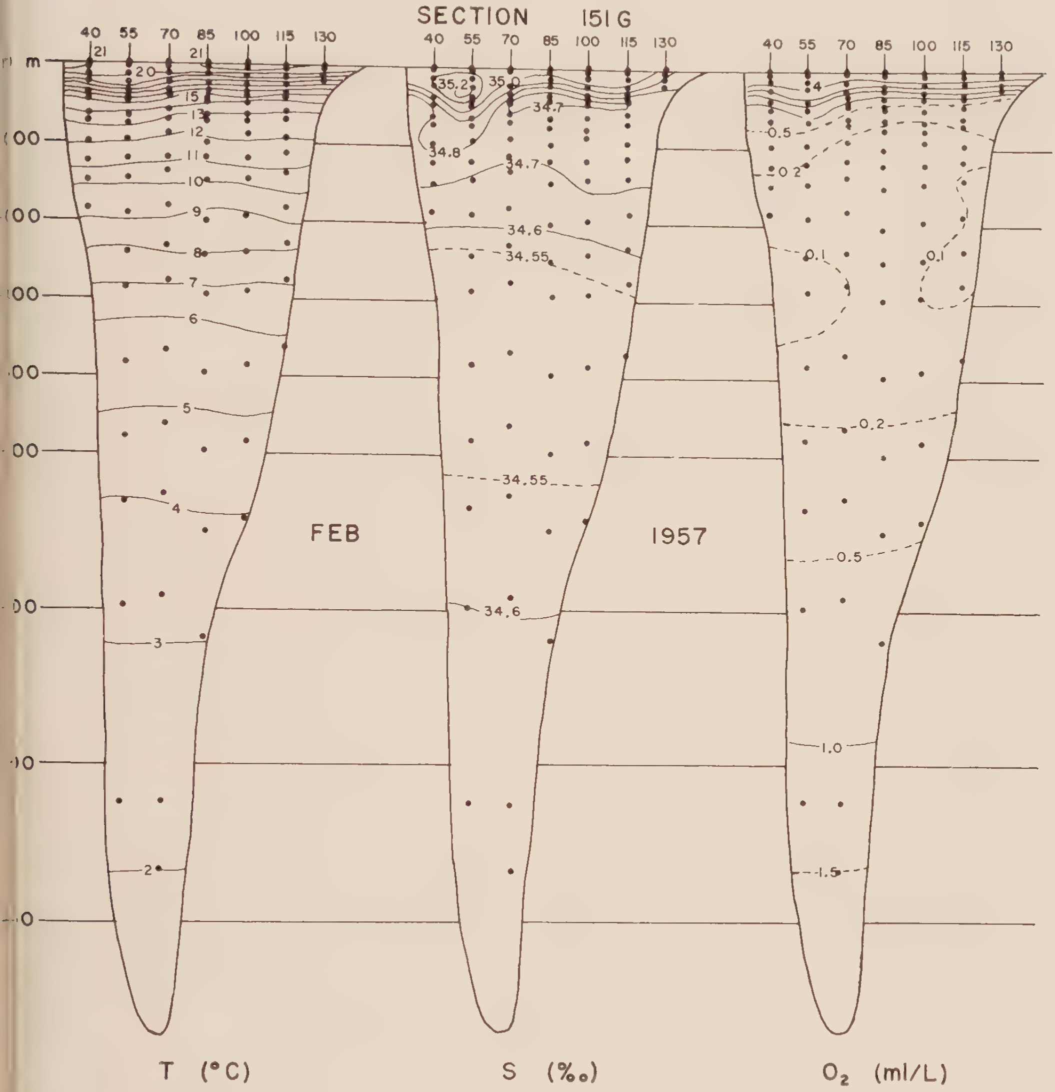


FIG. 10.—Distribution of temperature, salinity, and dissolved oxygen in th

ture at 1,000 m is 6°C, in salinity 0.4°/₀₀, and in dissolved oxygen content 1 ml/L. The deep salinity and oxygen minima, characteristic of the southern half of the Gulf, do not occur here. Instead, most of the deep water in the channel has the same features as that at the sill depth (250 m). In view of the strong tidal currents observed in the narrows, it is quite likely that the rather uniform temperatures, salinities, and oxygen concentrations below about 250 m are caused by tidal mixing. Above 250 m, the exchange of water between the northern and southern parts of th Gulf is unrestricted and the temperatures an salinities in the trench differ little from tho outside. During winter months, the stability the upper layers is weak and limited convectio of cold and high salinity water from the bays likely; the 35.8°/₀₀ salinity in the upper 75 m April 1959 is probably a remnant of this. Durin the summer, the thermocline in Ballenas Chann is well developed, as elsewhere in the Gulf.

Central Gulf (*Figs. 10 and 11*).—Here, th



ral and southern parts of the Gulf (Sections 127 G and 151 G of Fig. 1).

ths are great and the water is in open com-
nication with the Pacific Ocean to the south-
. In February, the isotherms, isohalines, and
lines of equal oxygen concentration in the
er layers rise toward the eastern coast. This is
bably due to upwelling induced by the north-
terly winds, which prevail during this time of
year. Between April and October, the thermo-
e is well developed; it reaches its maximum
ngth in August, when the temperature gra-
t between the surface and 150 m reaches 16°C.

In August, the salinity distribution in the upper layers is characterized by a minimum between 25 m and 75 m in the eastern half of the Gulf, and by a maximum off the Baja California coast. Since the only source of low salinity water is from the southeast, the salinity minimum probably indicates the presence of a northwestward-setting current between the above-mentioned depths. With regard to the salinity maximum along the western shore, this could either indicate the influence of Bahía Concepción, the salinity of which

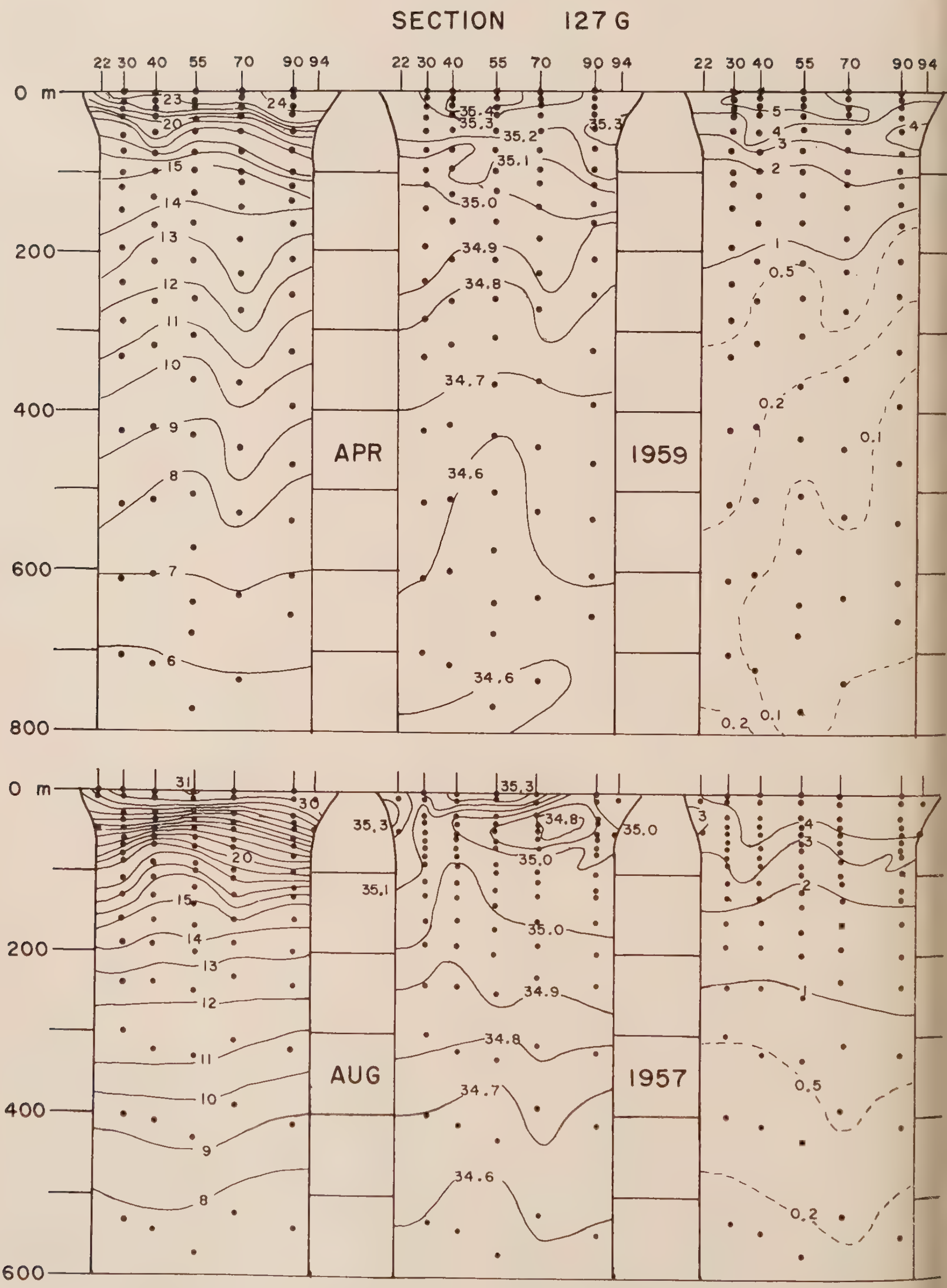
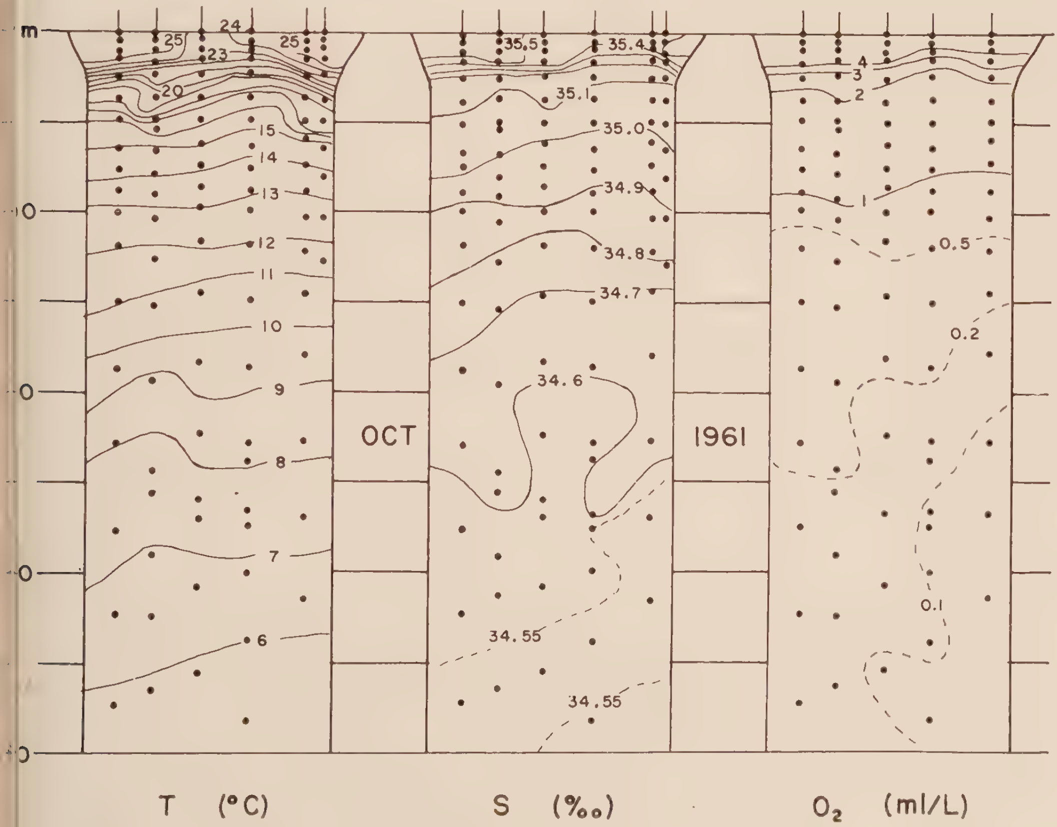


Fig. 11.—Distribution of temperature, salinity, and dissolved oxygen

very high (36.3°/oo), or it could represent the outhward movement of high-salinity water from he northern regions of the Gulf. The available ata are too incomplete to decide between the two ternatives.

Below the thermocline, the water is essentially he same as in the equatorial Pacific (Sverdrup, 941). The outstanding hydrographic features are he salinity minimum of slightly less than 4.55°/oo between 600 m and 1,000 m and the xygen minimum of less than 0.2 ml/L between 00 m and 800 m. The low concentrations of dislved oxygen, occasionally undetectable by dinary techniques (Winkler method), are haracteristic of the Gulf and the regions off the uthern coast of Mexico (Sverdrup, Johnson, d Fleming, 1946).

Southern Gulf (*Figs. 10 and 12*).—The region of the Gulf is characterized by a well developed thermocline throughout the year, and by numerous salinity maxima and minima in the upper layers. During February and April, the isotherms and isohalines ascend toward the Mexican mainland coast, suggesting upwelling by northwesterly winds. In winter and spring, a core of high salinity water occurs near the Baja California coast at a depth of 50 m; whereas in the central parts there is a salinity minimum of less than 34.7°/oo at about 100 m. The former probably represents southeasterly flow from the interior regions of the Gulf, and the latter, northwesterly flow from more southerly latitudes. During June and August, the upper salinity minimum extends from coast to coast, and is found between roughly 50 m and 100 m; the minimum values are mostly between 34.5°/oo and 34.7°/oo.



he central part of the Gulf (Section 127 G of Fig. 1).

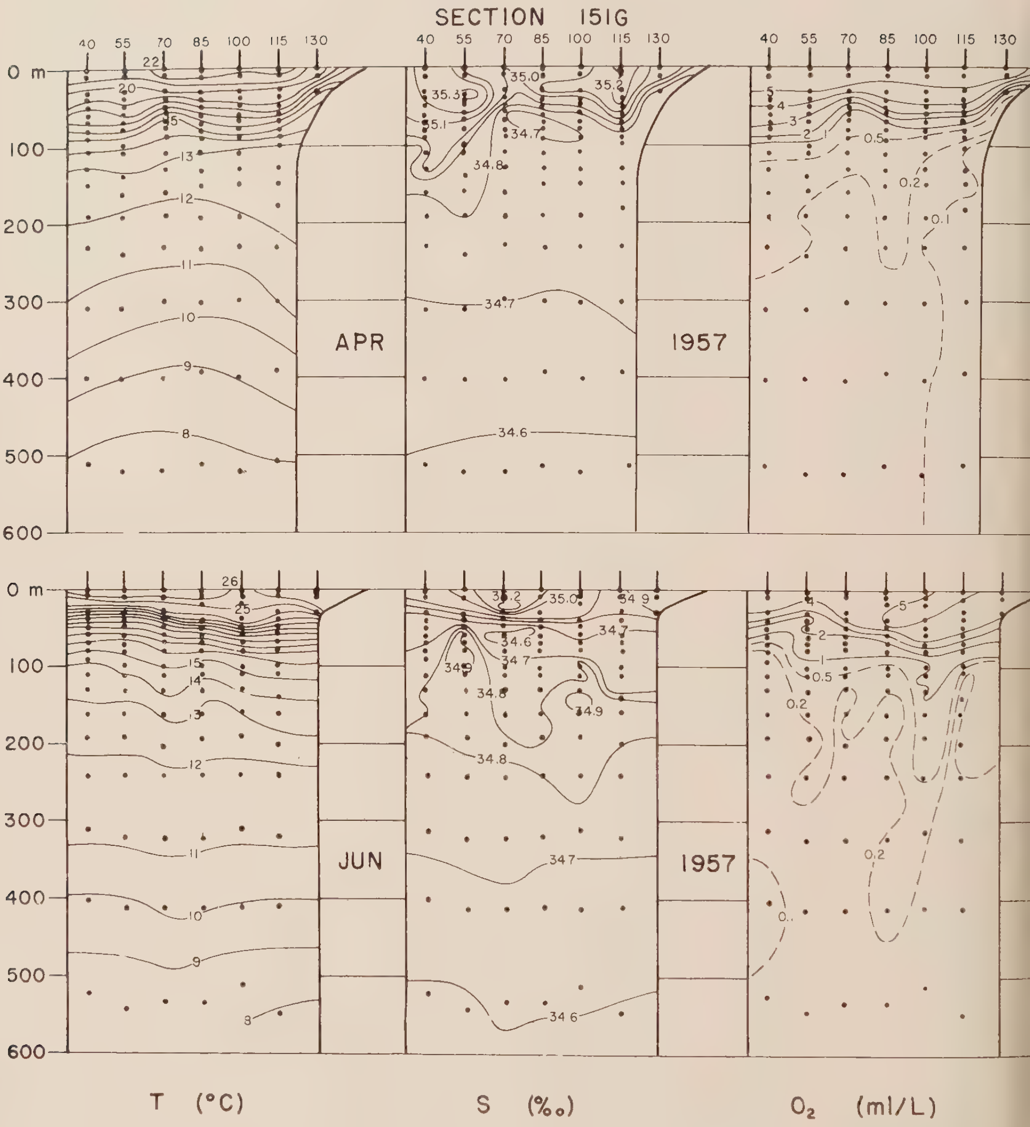
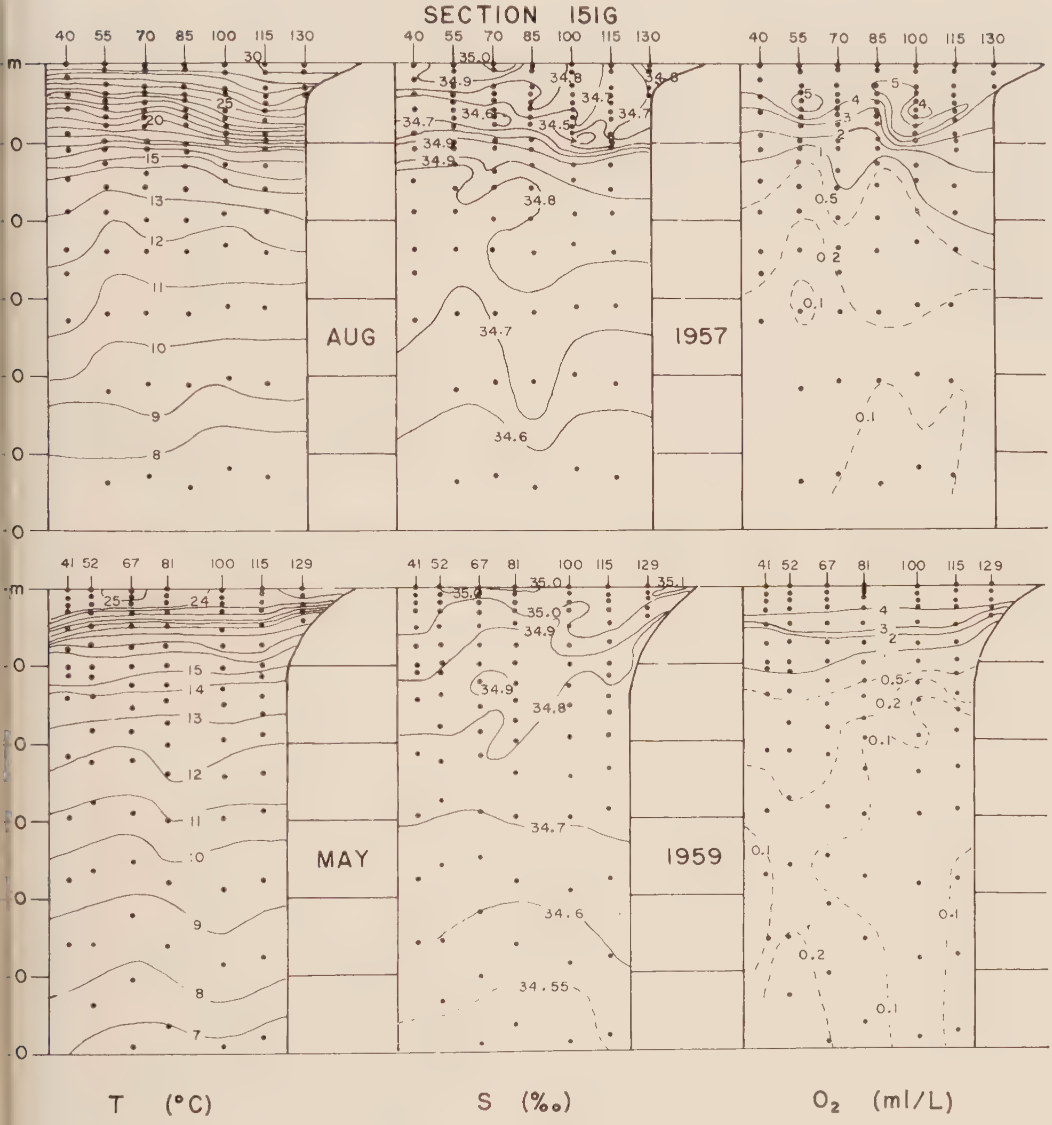


FIG. 12.—Distribution of temperature, salinity, and dissolv

Below about 200 m, the temperature, salinity, and oxygen distributions differ only slightly from those in the central Gulf. The main difference is the oxygen minimum, which is more pronounced, and which covers a larger depth interval. Here dissolved oxygen concentrations of less than 0.1 ml/L are common between 200 m and 600 m, and may occur on either side of the Gulf.

The region between *Islas Tres Marías and Is* *Socorro* (*Fig. 13*) is tropical and oceanic. T annual surface temperature range is only 4°C- 25°C–29°C. The thermocline lies mostly betwee 40 m and 100 m, the temperature decrease bei about 12°C. The upper salinity minimum is pr nounced and lies in the 50–100 m depth range most of the region. Near Isla Socorro, the influen



ygen in the southern part of the Gulf (Section 151 G of Fig. 1).

the California Current is indicated by the
v surface salinities of less than 34.0°/oo. Low
inities in the upper layers are also likely to be
ind between Islas Tres Marías and the main-
ad owing to heavy rainfall and runoff from
ay to October. Between 100 m and 300 m there
a salinity maximum with values ranging mostly
m 34.7°/oo to 34.8°/oo. Below 300 m, the

salinity distribution is the same as elsewhere in the tropical Pacific. The amount of dissolved oxygen decreases rapidly from 50 m to 100 m. In May 1959 the 0.1 ml/L isoline of dissolved oxygen occurred at 125 m and extended downward, in the eastern part, to about 500 m; in December 1956, the oxygen concentrations did not fall to 0.1 ml/L. These rather remarkable differences at

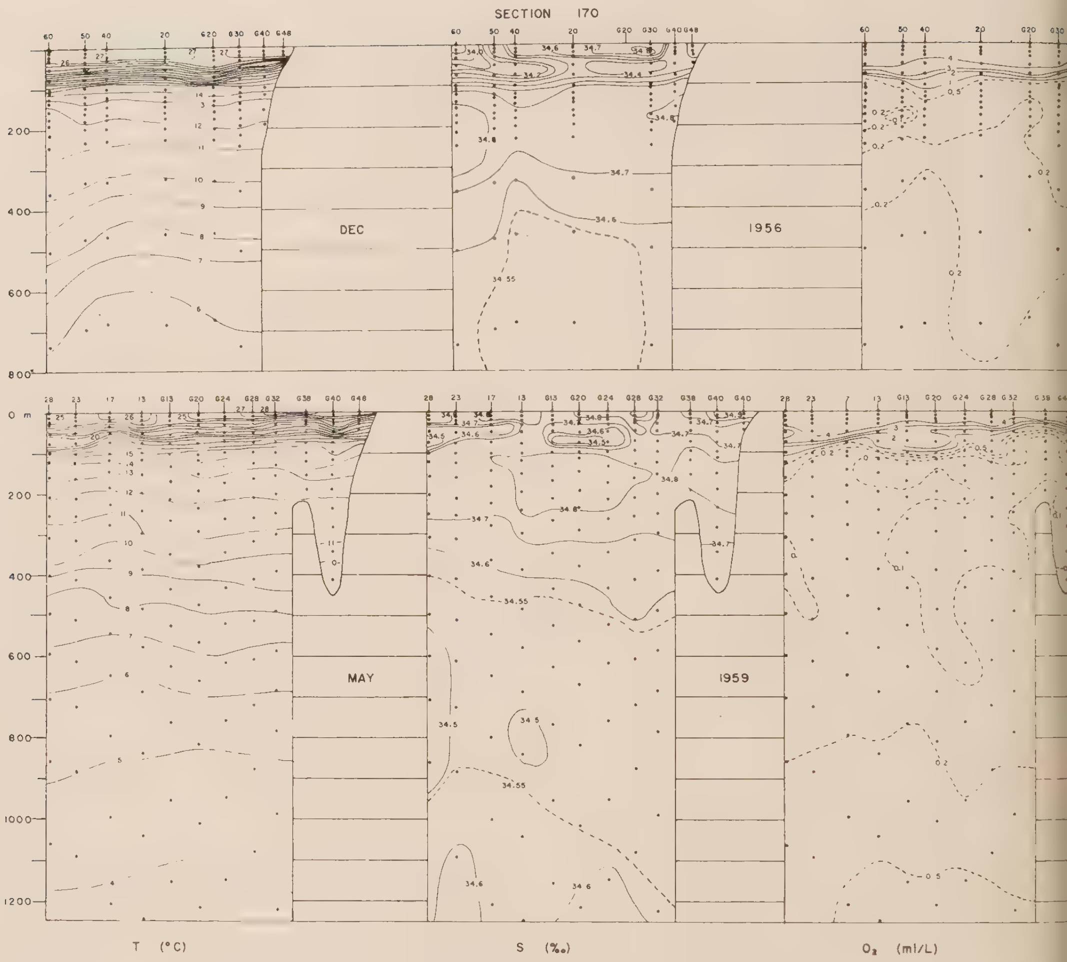


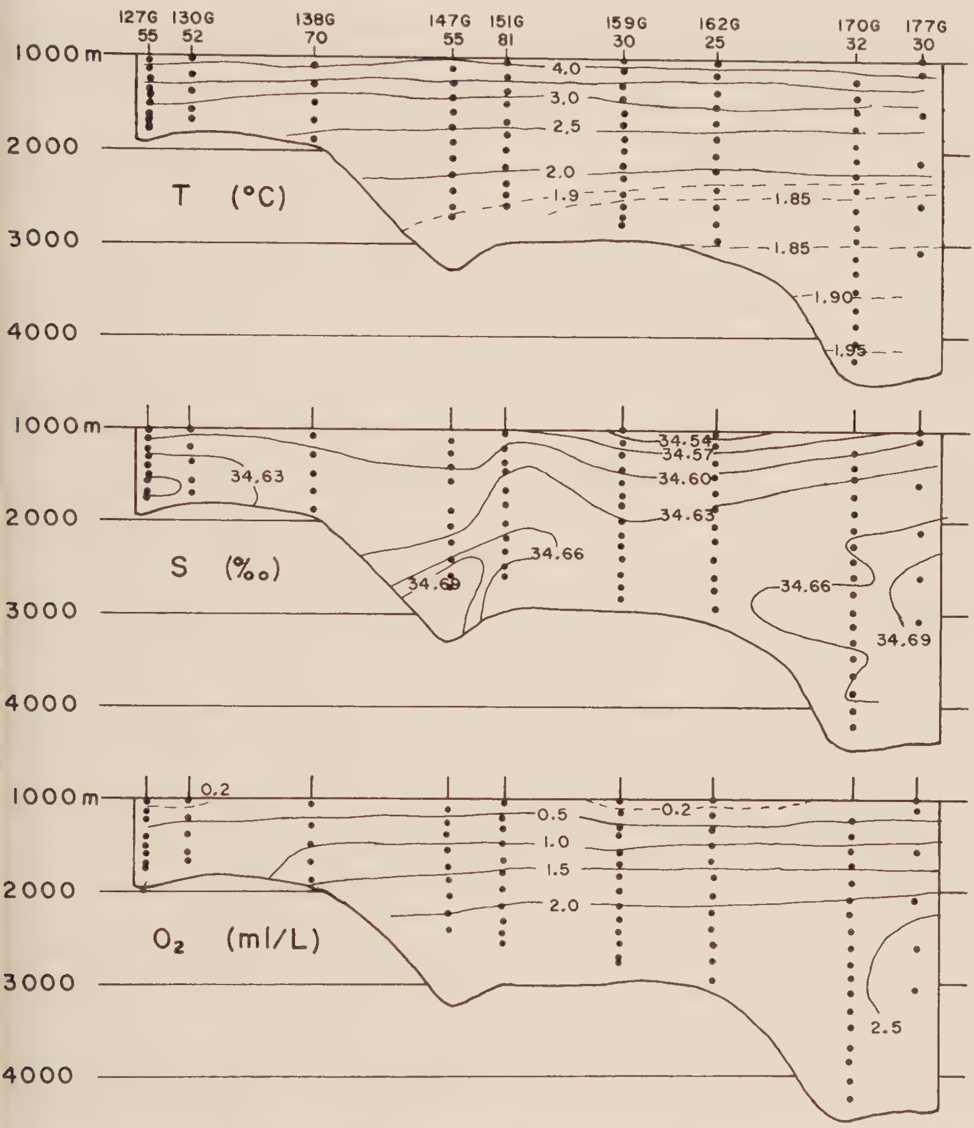
FIG. 13.—Distribution of temperature, salinity, and dissolved oxygen in a section extending from Islas Tres Marías to Isla Socorro (Section 170 G of Fig. 1).

depths shown by the two surveys indicate that temporal changes in dissolved oxygen between 100 m and 500 m may be appreciable. It is of interest to note that along the southern shore of Bahía Banderas (near Cabo Corrientes) no oxygen was found between 75 m and 500 m in May 1959.

Hydrographic conditions at great depths (*Fig. 14*).—Hydrographic conditions at depths below 1,000 m are illustrated in a longitudinal section running from Guaymas Basin to Cabo Corrientes. It is seen that there is a temperature minimum of slightly less than 1.85°C between 2,500 m and 3,000 m. From 3,000 m to the bottom, the temperature increases again at a rate of approximate 0.1°C per 1,000 m. The adiabatic temperatu increase between two depths is given by Defa (1961)

$$\Delta\theta = \int_{h_1}^{h_2} \frac{Tg}{Jc_p} \cdot \frac{1}{\alpha} \frac{\partial\alpha}{\partial T} dp$$

where $\Delta\theta$ is the temperature increase, T, the a solute temperature of the water, α, the speci volume, c_p, the specific heat at constant pressu g, gravity, J, the mechanical equivalent of he ($J = 4.1863 \times 10^7$ erg/cal), and dp, the pressu (depth) interval. If the pertinent values (Fofon



14.—Distribution of temperature, salinity, and oxygen at depths below 1,000 m along a section extending from Guaymas Basin (left) to Acapulco Trench (right). For station positions, see Fig. 1.

Froese, 1958) are inserted, it is found that the rved temperature increase between 3,000 m 4,000 m agrees closely with the adiabatic in- se calculated from the above equation.

ie salinity distribution between 1,000 m and bottom is surprisingly complex. The contour val of 0.03°/oo chosen here approaches the titration accuracy, and the validity of the details is not obvious. Nevertheless, there is a general tendency for the salinity to increase from 1,000 m toward the bottom.

The distribution of dissolved oxygen content shows that concentrations increase from about 0.2 ml/L at 1,000 m to about 2.4 ml/L at 4,000

m. It is noteworthy, however, that in the central part of the Gulf, oxygen concentrations at the bottom are much lower than at comparable depths (2,000 m) outside.

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The Spottail Shiner in Lower Red Lake, Minnesota

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ABSTRACT

On the basis of 14,654 spottail shiners (*Notropis hudsonius*) from Red Lakes, Minnesota, growth rates, strength of year classes, and food utilization were studied. Males and females had different body–scale relationships, and females grew faster than males. There was high correlation between water temperature and growth rate. Strength of year classes was closely related to size of spawning population. Food habits were related to food availability in both plankton and bottom fauna. Shiner eggs were significant items of food in larger shiners. Bottom organisms were selectively taken, and larger cladocerans were selected by large fish. Cladocerans were preferred to copepods.

INTRODUCTION

The spottail shiner, *Notropis hudsonius* Clinton), is the most abundant minnow in he Red Lakes, Minnesota, and is a major ood of the walleye, *Stizostedion vitreum* *itreum*, the most important commercial and port fish in these lakes. Because the spottail hiner is an important part of the walleye ood chain, and because the shoreline areas nhabited by the spotted shiner are also used y most of the commercial fishes in the Red akes for spawning and nursery areas, a nowledge of ecology and life history of the hiner will aid in the management of the Red akes commercial fishery (Smith and Kreftng, 1954). The objectives of this study were o describe the shiner's growth, abundance, nd food habits.

Physical characteristics of the Red Lakes ave been described by Magnuson and Smith 1963). Field work reported here was conducted as part of a general study made by the niversity of Minnesota and financed in part y the National Science Foundation and the ureau of Commercial Fisheries, Great Lakes nvestigations, Ann Arbor, Michigan.

MATERIALS AND METHODS

Field observations were made from early une to early September 1955–57. Fish were ollected in shoreline areas with a 6- by 50-foot, ¼-inch-mesh bag seine lined with 10-mesh bobbinet. Samples at 7-, 10-, 15-, and 20-foot depths were taken in a 10-foot otter trawl with the cod end lined with 8-mesh bobbinet. Samples of shiners were taken by bag seine at the East, South, and West stations and by otter trawl at the East and South stations (Figure 1). Seine hauls were made perpendicular to shore from 100–200 yards offshore to the beach. Trawl hauls were made parallel to shore at the various depths.

Plankton was sampled with a No. 10 (109 mesh/inch) net at each station immediately after the bag-seine hauls in 1956 and 1957. Bottom samples were taken at various depths at the South station in 1956 and at the East station in 1957 with a 12-inch Petersen dredge and rinsed in a 30-mesh sieve. Seine hauls and plankton tows were made at 4- to 16-day intervals at the East station and at 8- to 24-day intervals at the West station. Trawl hauls were made at 5- to 14-day intervals, and bottom samples were taken at 10- to 19-day intervals. All fish, plankton, and bottom samples were preserved in 10-percent formalin.

Total length measurements (tip of snout to end of compressed caudal fin) were made on 14,654 spottail shiners. Weights and stomach contents of 1,044 fish were recorded. Key scales were taken from 590 fish to determine body-length/scale-diameter relationships. Back-calculated lengths were determined by the nomograph and paper-strip method described by Carlander and Smith (1944).

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[1] Paper No. 5209 Scientific Journal Series, Minneta Agricultural Experiment Station, St. Paul, Minsota.

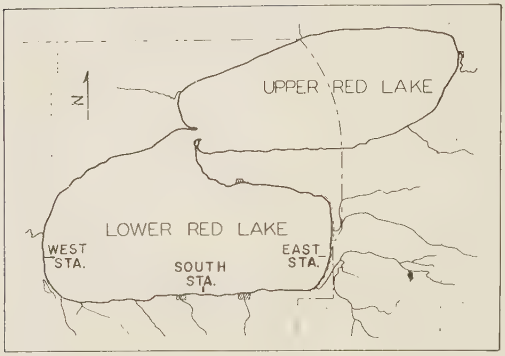

FIGURE 1.—Map of the Red Lakes, showing sampling stations.

GROWTH IN LENGTH

Shiners were easily separated by size into young-of-the-year, yearlings, and older fish. Age of older fish was determined from scales, and lengths at previous annuli were back-calculated for years prior to 1955.

Body–scale relationship

Scales were taken from seine- and trawl-caught fish at the East station in 1955, 1956, and 1957 and at the South station in 1956, and from seine-caught fish at the West station in 1956 and 1957. Three key scales were taken from the third scale row above the lateral line, the first directly below the anterior insertion of the dorsal fin and the other two immediately posterior. Scales were mounted in glycerin–gelatin and examined on an Eberbach scale projector (× 87). The average of two cephalocaudal scale diameters from each fish was plotted against total body length (35–117 millimeters), and regressions were linear.

Separate body-length/scale-diameter regressions calculated for male and female shiners (Figure 2) were significantly different at the 1-percent level ($F = 44.9$; d.f. $= 2{,}586$). These regressions were:

Males (226 fish): $L = 0.4398\ S + 11.0383$
Females (364 fish): $L = 0.3898\ S + 16.9824$

where L = total length in millimeters and S = scale diameter × 87 millimeters. No significant differences in body–scale regressions were found among the different areas or years within each sex, nor were the observed differences between the sexes due to any skewness in length distributions. Because the regressions for males and females were quite different (estimated total length for a 200-millimeter scale diameter was 99.0 millimeters for males and 94.9 for females), separate nomographs for each sex were used for back-calculation of lengths at time of formation of previous annuli.

Annuli were formed in the manner described by Marshall (1939) for the common shiner (*Notropis cornutus chrysocephalus*), with the annulus first appearing in the shorter anterior field. The first annulus was formed late in June, and subsequent annuli were formed after spawning (second week in July). Spawning first occurred at the beginning of the third summer of life.

Validation of the scale method

Validity of the scale method for use with the spottail shiner was first checked by noting the agreement of back-calculated lengths with empirical lengths at the time of annulus for-

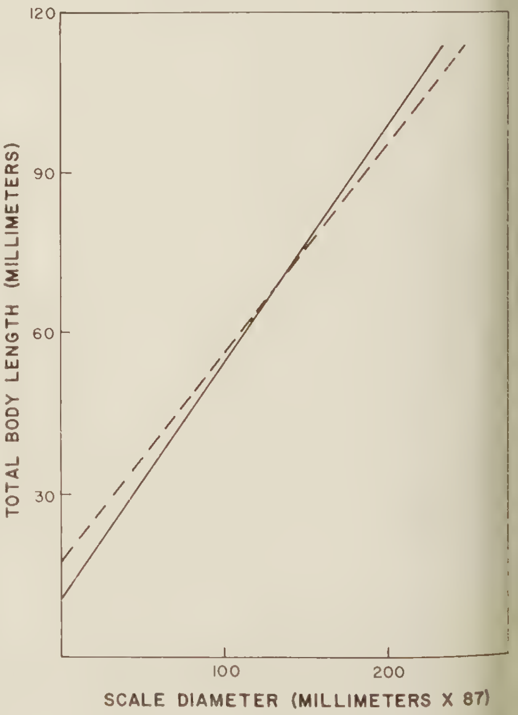

FIGURE 2.—Body-length/scale-diameter regression for male and female spottail shiners at Lower Red Lake, Minnesota.

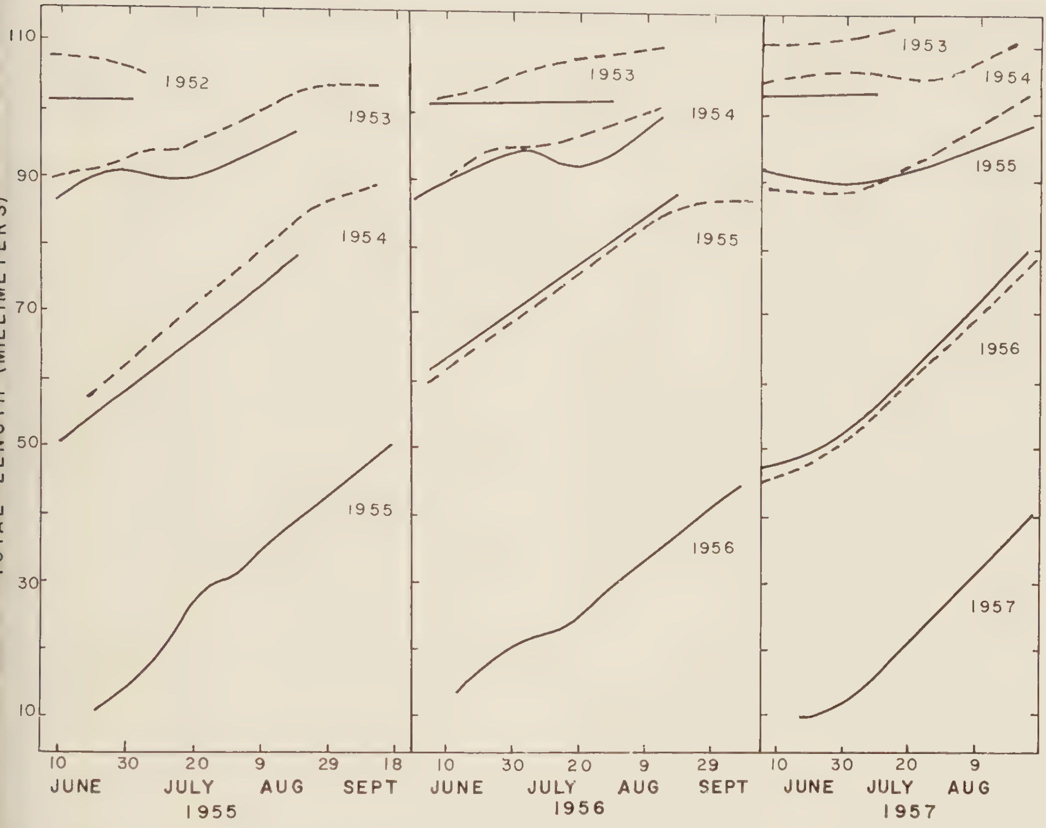

FIGURE 3.—Observed growth curves for all age groups of spottail shiners collected in 1955–57 at Lower Red ıke (males—solid line; females—dashed line).

ation (Table 1). Back-calculated total ngths were not significantly different from npirical lengths (chi-square = 2.78; d.f. = 1). Secondly, the size groups were followed rough each growing season, 1955–57, and it as found that only one annulus was formed ch year. Finally, years of good or poor growth showed good agreement between males and females and in fish from different years of collection.

ABLE 1.—*Empirical and back-calculated total lengths at time of annulus formation, spottail shiner, Lower Red Lake, 1955–57*[1]

x nd year	Annulus I Empirical	Annulus I Calculated	Annulus II Empirical	Annulus II Calculated	Annulus III Empirical	Annulus III Calculated
les						
955	55.0	57.5	90.0	82.0	—	—
956	62.0	58.5	93.5	88.0	—	—
957	48.0	50.5	90.0	85.5	—	—
males						
955	55.0	59.0	93.5	88.0	108.0	106.0
956	60.0	58.0	95.0	93.5	104.5	105.0
957	49.0	52.5	90.0	88.5	102.0	99.5

Empirical length measured to nearest 0.5 millimeter; culated length rounded to nearest 0.5 millimeter.

Seasonal growth

Curves of seasonal growth of each year class were constructed for all fish captured in 1955, 1956, and 1957 (Figure 3). No differences were found among fish from the various stations, and all samples for each year class were combined. First-year growth was the same in both sexes, but in following years females grew faster. The oldest fish taken were 4 years old (three annuli during the spawning season), and most of these were females. There was an apparent decrease in the total length of 2-year-old fish taken in successive collections until after time of spawning and annulus formation; thereafter an increase in length occurred (Figure 3). This phenomenon, which was observed in both

TABLE 2.—*Total lengths of spottail shiners at time of annulus formation, Lower Red Lake, 1951–57*

[Measurements in millimeters]

Year class	Males				Females			
	I	II	III	IV	I	II	III	IV
1957	56.2[1]	—	—	—	57.3[1]	—	—	—
1956	50.3	82.0[1]	—	—	52.7	84.6[1]	—	—
1955	58.5	85.5	98.5[1]	—	58.0	88.4	103.5[1]	—
1954	57.4	88.2	102.5[2]	104.0[1]	58.9	93.4	107.0[2]	113.5[1]
1953	55.2	82.1	96.3	103.0[2]	58.5	87.9	105.1	113.0[2]
1952	60.6	89.4	102.5[2]	—	57.7	90.0	106.0	113.0[2]
1951	—	—	—	—	63.3	96.5	109.5	113.0[2]
Grand average	56.4	85.4	100.0	103.0	58.1	90.1	106.2	113.1

[1] Estimated from lengths on August 29, 1957.
[2] Observed lengths during spawning season before annulus formation.

males and females, was substantiated by back-calculated lengths to annulus formation. The discrepancy is believed to be due to a greater post-spawning mortality of the larger individuals which apparently arrived at the spawning area first. The decrease in size was also noted in the 3-year-olds, an age group represented by few fish.

Growth during 1951–57

Because the empirical lengths on the date of annulus formation agreed well with back-calculated lengths, observed lengths were used to estimate the length at annulus formation in cases where no fish in an age group were captured after annulus formation. Growth in years prior to 1955 was estimated from back-calculated lengths. Total growth in 1957 was estimated from the length on August 29, using the mean of ratios between total season's growth and empirical length on August 29 in 1955 and 1956 as follows:

	1st year	*2nd year*	*3rd year*
Male	1.34	1.00	1.00
Female	1.37	1.05	1.00

Grand average calculated lengths were computed for both sexes for the period 1951–57 (Table 2). Females grew faster than males at all ages, although empirical data during 1955, 1956, and 1957 showed no difference between the sexes during the first year. This discrepancy may be caused by a higher post-spawning mortality among the larger males.

Variations in seasonal growth

Goodness or poorness of growth in different seasons was expressed as percentage deviation from mean annual growth during the 6-year period 1952–57, after the method described by Hile (1941) (Table 3). Both sexes showed similar deviations from average seasonal growth, with the largest discrepancy in 1952 when males were represented by only four fish. The best growth year was 1955, and the poorest was 1956. These variations are similar to those found for first-year walleyes (Smith and Pycha, 1960) and trout-perch, *Percopsis omiscomaycus* (Magnuson and Smith, 1963) in Red Lakes (Table 3).

TEMPERATURE AND GROWTH RATE

Air temperature records are available for all years from the U. S. Weather Bureau station at the town of Red Lake on the south shore of the lake. Water temperatures were recorded at the outlet of Red Lake (Red Lake River) in 1956 and 1957. From daily mean water temperatures at the outlet and simultaneous mean air temperatures at Red Lake $\left(\frac{\text{maximum} + \text{minimum}}{2}\right)$, factors were calculated to estimate daily mean water temperatures from daily mean air temperatures for 1952 through 1955. June 15 was chosen as

TABLE 3.—*Percentage deviation from mean annual growth in spottail shiner, trout-perch, and young-of-the-year walleye from Lower Red Lake during 1952–57*

Year	Shiner		Trout-perch[1]		Walleye[2]
	Male	Female	Male	Female	Young-of-year
1952	+7.89	−0.87	−1.02	−1.64	+3.4
1953	−1.44	−1.75	−6.90	−3.82	−2.4
1954	−1.08	−1.27	+4.72	+0.07	−5.4
1955	+4.99	+6.66	+10.72	+10.08	+3.4
1956	−7.21	−4.28	+0.39	−10.84	−10.0
1957	−3.12	+1.48	—	—	—

[1] Magnuson and Smith (1963), calculated on 1947–56 base.
[2] Smith and Pscha (1960), calculated on 1940–56 base.

TABLE 4.—*Percentage deviation from mean number of degree-days with water temperatures above 50° F. (June 15–August 31), and percentage deviation from mean annual growth of spottail shiners, Lower Red Lake, 1952–57*

Year	Water temperature		Spottail shiner growth		
	Degree-days above 50° F.	Percentage deviation	Percentage deviation from mean		
			Male	Female	Sexes combined
1952	1,623.3	−3.82	+7.89	−0.87	+3.56
1953	1,711.2	+1.39	−1.44	−1.75	−1.60
1954	1,684.2	−0.21	−1.08	−1.27	−1.18
1955	1,828.5	+8.34	+4.99	+6.66	+5.83
1956	1,574.8	−6.70	−7.21	−4.28	−5.75
1957	1,704.5	+0.99	−3.12	+1.48	−0.82

TABLE 5.—*Correlation coefficients (r) between water temperature degree-days above 50° F. and growth of spottail shiners, Lower Red Lake, 1952–57—expressed as correlations between percentage deviations*

Correlation	*r*	Probability
Water temperature and combined growth	+0.671	<0.20
Water temperature and female growth	+0.902	<0.05
Water temperature and male growth	+0.388	<0.50
Water temperature and male growth (except 1952)	+0.967	<0.01

the beginning of the growth year because it is near the spawning date, and growth in older fish does not begin until June 15 or later. August 31 was selected as the end of the growth period because growth which occurred after this date was a small proportion of total season's growth.

Water temperature degree-days above 50° F. were added during the growth period (June 15–August 31), and percentage deviations from mean accumulated degree-days were calculated (Table 4). The correlation (r) between percentage deviation from mean annual growth increment and percentage deviation from mean accumulated degree-days was +0.902 ($p < 0.05$) for females and +0.967 ($p < 0.01$) for males, 1952 excepted (Table 5).

Growth rates of young-of-the-year and yearling shiners were calculated for 1-week intervals from June 15 to August 30, and were compared with weekly water temperature experience as measured by degree-days accumulated above 50° F. Growth rate was defined as the ratio of the weekly increment in total length to the length at the beginning of the week. Total lengths at the end of each week were read directly from the growth curves (Figure 3) for young-of-the-year and female yearling shiners (Table 6). Within each week, degree-days and percentage increments in total length for each age group were ranked from 1 to 3 in 1955–57. Ranks of growth rate were compared with corresponding ranks of degree-day summation each week and were found to be in close agreement for both first and second summer's growth through August 2. Average rank correlation coefficients (r_s) were +1.000 ($p < 0.01$) during the first season and +0.857 ($p < 0.05$) during the second. During the period August 3–30, however, correlations were not significant.

LENGTH–WEIGHT RELATIONSHIP

Weights were determined for 1,044 fish with total lengths from 7 through 117 millimeters collected at the East station in 1956 and 1957 and at the West station in 1957. Mean weights at each 1-millimeter total length interval were computed for fish in each

TABLE 6.—*Total lengths of young-of-the-year and female yearling spottail shiners and accumulated water temperatures in degree-days above 50° F. during 1-week intervals, June 15–August 30, 1955–57, Lower Red Lake*

Week ending:	1955			1956			1957		
	Total length (millimeters)		Degree-days	Total length (millimeters)		Degree-days	Total length (millimeters)		Degree-days
	Y.-of-y.	Yearling		Y.-of-y.	Yearling		Y.-of-y.	Yearling	
June 14	–	54.5	–	–	60.0	–	–	48.5	–
21	10.5	57.5	135.0	14.0	62.5	140.5	10.5	50.0	97.8
28	12.5	60.5	121.6	16.5	65.2	121.0	11.5	51.8	102.1
July 5	16.8	63.5	156.5	18.5	67.5	127.0	13.5	54.5	133.0
12	21.0	66.4	147.0	20.5	70.2	115.0	17.0	57.7	157.0
19	25.2	69.4	180.1	22.0	72.6	147.5	20.5	60.8	188.5
26	29.0	72.4	190.5	23.4	75.1	150.5	24.5	63.8	195.0
August 2	32.0	75.4	198.5	25.5	77.4	150.5	28.0	67.3	209.0
9	35.0	78.4	179.8	28.5	80.0	163.4	31.5	70.7	175.4
16	38.0	81.4	184.5	31.3	82.5	168.4	35.5	74.0	166.2
23	41.0	84.4	164.0	34.5	85.0	126.5	39.0	77.5	139.0
30	44.3	86.4	154.5	37.5	86.2	145.0	42.5	81.0	121.0

TABLE 7.—*Mean relative condition factors* (K_n) *of seine- and trawl-caught spottail shiners 21–117 millimeters total length, East and West stations, Lower Red Lake, 1956–57*

[Numbers of fish in parentheses]

Station, year, and gear	Age group			
	0	I	II and older	
			Male	Female
East—1956				
Seine	0.940 (76)	0.997 (154)	0.965 (3)	1.041 (15)
Trawl	1.015 (33)	1.033 (64)	—	1.058 (10)
East—1957				
Seine	1.006 (101)	0.993 (135)	0.971 (36)	1.028 (40)
Trawl	1.012 (32)	1.003 (60)	0.945 (9)	0.989 (24)
West—1957				
Seine	0.995 (60)	1.004 (64)	1.030 (24)	1.022 (28)

station-year collection, and unweighted mean weights at each 1-millimeter interval were used for calculation of the following length–weight regression:

$$\log W = 2.98913 \log L - 2.04449$$

where W = weight in grams and L = length in millimeters.

The conditions of all spottail shiners with total lengths greater than 21 millimeters from the two years and areas were compared by use of the relative condition factor (K_n) as defined by LeCren (1951):

$$(K_n) = \frac{W}{W_1}$$

where W = weight at capture and W_1 = weight calculated from the length–weight regression. Mean relative condition factors were compared between areas and years within age groups, between seine- and trawl-caught fish within areas and between years, and between sexes within areas and years.

Relative condition factors within any single group of shiners were approximately normally distributed, and differences between means were tested for significance with the *t* test (Table 7). Differences significant at the 5-percent level were found in three comparisons. Young-of-the-year and yearlings caught by trawl at 10–20 feet were heavier than seine-caught fish at the East station in 1956, and young-of-the-year captured in the seine at the East station were heavier in 1957 than in 1956. Mean relative condition factors for females were usually higher than those for males, but the differences were not significant.

ABUNDANCE OF SPOTTAIL SHINER, 1955–57

A regression method of analysis of bag-seine catch data was used in the present study. This method employs a regression calculated from the catches of seine hauls made on a series of dates extending over a period of several weeks in a particular season. Extension in time minimizes the influence of variations due to natural mortality and day-to-day changes in ecological conditions at the seining sites. Multiple regression analysis which includes independent ecological variables may be applied. In the analysis of spottail shiner data, regressions were plotted from catches taken in the first of several seine hauls made at 3- to 5-day intervals at the East station during each season. The first seining date used in any season was the one immediately prior to the date of largest catch, and the last was the second date on which no fish were taken. Significance of differences between regressions was determined by regression analysis. Regressions were plotted for four age groups (0, I, II, III) from catches in 1955–57. Numbers of fish per 100 yards of seine haul of 30-foot width were expressed as the logarithm of the number plus one. Numbers of young-of-the-year were estimated at time of peak vulnerability to the bag seine, while the numbers in older groups present on June 1 of each year were estimated by extrapolation from the regression lines.

The number of young-of-the-year was highest in 1957 and lowest in 1955, with differences among years significant at the 5-percent level (Table 8). Catches of I-annulus fish, however, indicated that there was no difference between the sizes of the 1955 and 1956 year classes, and that the 1954 year class was significantly smaller than those of 1955 and 1956. The 1953 and 1954 year classes as estimated from II-annulus shiners were significantly smaller than the 1955 year class. These analyses indicate that 1953 and 1954 were weak year classes, 1955 and 1956 were average, and 1957 was strong. Estimates of relative year-class strengths of shiners differ from those found for the trout-perch of Lower Red

TABLE 8.—*Abundance of young-of-the-year spottail shiners at time of peak vulnerability and of I-, II-, and III-annulus fish present on June 1, East station, Lower Red Lake, 1955–57—expressed as number per 100 yards of seine haul*

Age group	Year	Estimated number	95-percent confidence limits
0	1955	27	1– 393
	1956	1,774	747– 4,209
	1957	25,147	9,620–65,732
I	1955	42	9– 183
	1956	748	44–12,557
	1957	756	111– 5,132
II	1955	10	3– 30
	1956	8	0– 52
	1957	224	58– 860
III	1955	2	0– 7
	1956	12	0– 135
	1957	6	1– 23

Lake (Magnuson and Smith, 1963) where 953, 1955, and 1957 were strong and 1954 nd 1956 were weak.

Strengths of year classes were closely reated to the sizes of the spawning populations n 1955, 1956, and 1957. Approximately the ame numbers of spawners were present in 955 and 1956, and both produced average ear classes; whereas in 1957, 14 times as any spawners produced 12 times as many oung-of-the-year as in 1956.

FOOD HABITS

Stomach analyses were made on fish from eine samples taken at the East station in 1956 nd 1957 and at the West station in 1957, and rom trawl samples collected at the East staion in 1956 and 1957. The section of the -shaped digestive tract from the pharynx to e first loop was designated as the "stomach," nd its contents were counted in a Sedgwickafter cell with appropriate magnification. ince most of the food items were broken, me organisms, particularly algae, may not ve been recognized. Stomach contents were corded as numbers of organisms, and comrisons were made on the basis of percentage currence and average number per stomach. e groups of organisms in the stomach conts are shown in Table 9.

Boesel (1938) and McCann (1959) reorted that most young-of-the-year spottail iners ate the same organisms as the adults. the present study there was a definite ange in food selection with increase in size which became evident at about 70 millimeters total length (Table 10). Crustacea were most important in the smaller fish, but in fish larger than 70 millimeters insects predominated. Rotifers and algae were used by a significant number of fish only in the size group below 10 millimeters. Larger organisms such as molluscs, mayfly nymphs (mostly *Hexagenia*), Corixidae, and fish were rarely found in young-of-the-year shiners (less than 70 millimeters, total length). *Cyclops*, although used by fish in most size groups, was common only in the smaller fish.

As the fish increased in size the smaller Cladocera became less numerous in comparison to the larger species. In fish below 70 millimeters, *Chydorus*, *Daphnia*, and *Ceriodaphnia* made up 46, 29, and 10 percent, respectively, of Cladocera; while in larger fish *Daphnia* and *Eurycercus* comprised 74 and 22 percent (Table 11). Fish larger than 49 millimeters in length ate spottail shiner eggs with the incidence in the largest group (110–117 millimeters) being 33.3 percent.

TABLE 9.—*Food items taken by spottail shiners, Lower Red Lake, 1955–57*

- Algae
  - *Pediastrum simplex*
  - *Pediastrum Boryanum*
  - *Pediastrum duplex*
  - *Stephanodiscus* sp.
  - *Fragilaria crotonensis*
  - *Amphora* sp.
  - *Anacystis cyanea*
  - *Gloeotrichia echinulata*
- Rotifera
  - *Keratella chochlearis*
  - *Keratella quadrata*
  - *Asplanchna priodonta*
  - *Lepadella* sp.
  - *Lecane* sp.
- Crustacea
  - Cladocera
    - *Leptodora kindtii*
    - *Sida crystallina*
    - *Latona setifera*
    - *Diaphanosoma brachyurum*
    - *Daphnia pulex*
    - *Daphnia longispina*
    - *Simocephalus* sp.
    - *Ceriodaphnia lacustris*
    - *Ceriodaphnia reticulata*
    - *Ceriodaphnia megalops*
    - *Bosmina longirostris*
    - *Eurycercus lamellatus*
    - *Alona* sp.
    - *Pleuroxus* sp.
    - *Chydorus sphaericus*
  - Ostracoda
    - *Cypria* sp.
  - Copepoda
    - *Epischura lacustris*
    - *Diaptomus reighardi*
    - *Cyclops bicuspidatus*
    - *Mesocyclops edax*
- Amphipoda
  - *Hyalella azteca*
- Insecta
  - Ephemeroptera
    - *Hexagenia* nymphs
    - *Ephemera* nymphs
  - Odonata
    - Coenagrionidae (nymphs)
  - Hemiptera
    - Corixidae (adult and instar)
  - Coleoptera
    - Dytiscidae (adult)
  - Trichoptera
    - Hydropsychidae (larva and pupa)
    - Leptoceridae (larva and pupa)
  - Diptera
    - Chironomidae (larvae, pupa, adult)
      - *Pentaneura* sp.
      - *Calopsectra* sp.
      - *Tendipes* sp.
      - *Cryptochironomus* sp.
      - *Glyptotendipes* sp.
      - *Polypedilum* sp.
    - Ceratopogonidae (larva and pupa)
- Arachnida
  - Hydracarina
  - Arachna (adult)
- Mollusca
  - Gastropoda
  - Pelecypoda
    - *Sphaerium* sp.
    - *Pisidium* sp.
- Osteichthyes
  - *Notropis hudsonius* (egg and young)

TABLE 10.—*Food of 1,042 spottail shiners, Lower Red Lake, East and West stations, 1956 and 1957*

[Expressed as average number per stomach and percentage occurrence (parentheses)]

	Total length interval (millimeters)											
	7–9	10–19	20–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99	100–109	110–117
Algae	1.0 (30)	0.1 (1)	0.9 (8)	7.0 (9)	0.2 (1)	0.1 (4)	0.0 –	0.1 (3)	0.1 (1)	0.0 –	0.2 (9)	0.0 –
Rotifera	1.4 (40)	0.1 (1)	0.1 (6)	0.1 (3)	0.0 –	0.0 –	0.0 –	0.0 –	0.0 –	0.1 (1)	0.1 (2)	0.0 –
Cladocera	5.7 (100)	13.1 (82)	10.4 (74)	25.6 (79)	49.5 (85)	69.7 (84)	34.2 (55)	5.5 (17)	10.2 (23)	7.1 (28)	1.4 (18)	0.1 (11)
Copepoda	3.7 (60)	2.3 (21)	2.5 (13)	2.7 (18)	4.0 (10)	0.1 (1)	0.0 –	0.1 (1)	0.1 (2)	0.1 (1)	0.0 –	0.1 (11)
Ostracoda	0.0 –	0.8 (8)	0.0 –	0.1 (3)	0.4 (6)	0.7 (7.4)	0.1 (1)	0.1 (5)	0.2 (8)	0.1 (4)	0.1 (2)	0.0 –
Hyalella	0.0 –	0.0 –	0.0 –	0.1 (1)	0.1 (2)	0.0 –	0.1 (1)	0.2 (6)	0.1 (2)	0.1 (1)	0.1 (4)	0.0 –
Hydracarina	0.0 –	0.2 (7)	0.2 (8)	0.1 (5)	0.3 (7)	0.3 (3)	0.2 (4)	0.2 (5)	0.1 (5)	0.1 (2)	1.5 (7)	0.0 –
Ephemeroptera	0.0 –	0.0 –	0.0 –	0.0 –	0.0 –	0.0 –	0.0 –	0.1 (1)	0.1 (7)	0.1 (3)	0.2 (20)	0.2 (22)
Corixidae	0.0 –	0.0 –	0.0 –	0.1 (1)	0.0 –	0.1 (1)	0.2 (7)	0.1 (2)	0.1 (5)	0.3 (12)	0.5 (9)	2.1 (11)
Trichoptera	0.0 –	0.1 (1)	0.0 –	0.1 (2)	0.1 (3)	0.0 –	0.1 (3)	0.4 (14)	0.5 (18)	0.3 (6)	0.2 (9)	0.3 (11)
Chironomidae	0.1 (10)	0.4 (11)	0.7 (23)	1.3 (16)	1.3 (24)	0.2 (9)	1.2 (12)	2.0 (36)	2.9 (44)	1.2 (25)	1.3 (27)	14.2 (56)
Other Insecta	0.1 (10)	0.0 –	0.1 (1)	0.1 (1)	0.0 –	0.1 (1)	0.1 (4)	0.1 (2)	0.1 (2)	0.1 (2)	0.1 (7)	0.0 –
Mollusca	0.0 –	0.0 –	0.0 –	0.0 –	0.0 –	0.0 –	0.1 (4)	0.1 (4)	0.1 (5)	0.1 (4)	0.4 (4)	0.1 (11)
Fish	0.0 –	0.0 –	0.0 –	0.0 –	0.0 –	0.0 –	0.0 –	0.0 –	0.1 (1)	0.1 (2)	0.0 –	0.0 –
Fish eggs	0.0 –	0.0 –	0.0 –	0.0 –	0.0 –	0.2 (3)	0.7 (12)	1.9 (12)	0.9 (11)	4.1 (26)	1.8 (24)	8.1 (33)
Total stomachs	10	73	86	150	90	81	74	156	154	105	45	9
Percentage empty	0.0	2.7	5.8	8.7	7.1	4.9	23.0	30.1	25.3	23.8	22.2	22.2

Depth of capture and food use

Food of shiners taken with the seine and trawl at 0–7 feet was compared with that of fish taken with the trawl at 10–20 feet. Fish below and above 70 millimeters total length were considered separately (Table 12). Fish captured at deeper levels contained more Cladocera, Copepoda, Ostracoda, Ephemeroptera, Trichoptera, chironomid larvae, and chironomid pupae than those taken in shallow water, which ate more fish eggs, chironomid adults, all of the Corixidae, and had a higher percentage of empty stomachs. Differences in

TABLE 11.—*Percentage of total Cladocera represented by each genus in the food of spottail shiners above and below 70 millimeters total length, Lower Red Lake, 1956–57—expressed as percentage of total number in each size group*

	Size group (millimeters)	
Genus	7–69	70–117
Alona	0.1	0.0
Bosmina	1.8	0.1
Ceriodaphnia	9.7	0.0
Chydorus	46.2	0.3
Daphnia	28.6	73.8
Diaphanosoma	4.0	0.6
Eurycercus	7.5	21.7
Latona	0.1	0.1
Leptodora	0.4	0.8
Sida	1.5	2.4
Other	0.1	0.1

TABLE 12.—*Food of spottail shiners captured at 0–7 feet and 10–20 feet, East station, Lower Red Lake, 1956 and 1957 combined—expressed as average number of organisms per stomach and percentage occurrence (parentheses)*

Item	Depth			
	0–7 feet		10–20 feet	
	Total length (millimeters)		Total length (millimeters)	
	7–69	70–117	7–69	70–117
Cladocera	21.3 (75)	4.5 (22)	70.2 (77)	5.1 (19)
Copepoda	2.0 (12)	<0.1 (2)	4.7 (25)	<0.1 (2)
Ostracoda	0.2 (3)	0.3 (7)	0.3 (6)	0.3 (11)
Hyalella	<0.1 (1)	0.1 (5)	<0.1 (3)	<0.1 (3)
Hydracarina	0.2 (7)	0.1 (6)	<0.1 (2)	0.6 (3)
Ephemeroptera	0.0 –	<0.1 (3)	0.0 –	0.2 (15)
Corixidae	<0.1 (2)	0.2 (7)	0.0 –	0.0 –
Trichoptera	<0.1 (2)	0.4 (13)	0.1 (2)	0.7 (22)
Chironomidae larvae	0.5 (12)	0.8 (18)	2.5 (28)	3.9 (68)
Chironomidae pupae	<0.1 (2)	0.1 (3)	<0.1 (2)	0.8 (17)
Chironomidae adult	0.1 (4)	1.0 (8)	<0.1 (2)	<0.1 (3)
Mollusca	<0.1 (1)	0.1 (3)	0.0 –	0.2 (7)
N. hudsonius egg	0.1 (2)	2.8 (18)	0.1 (1)	0.1 (5)
Number of stomachs	362	261	104	121
Percentage empty	9.1	27.6	4.8	12.4

TABLE 13.—*Utilization of crustaceans and insects by spottail shiners taken 0–7 feet deep at East and West stations, Lower Red Lake, 1956 and 1957—expressed as average number per stomach and percentage occurrence (parentheses)*

Station	Year	Total length interval (millimeters) beginning at:									
		10	20	30	40	50	60	70	80	90	100
						CRUSTACEA					
East	1956	0.4 (25)	13.7 (66)	42.0 (98)	23.7 (85)	20.9 (57)	36.6 (49)	1.3 (21)	2.8 (32)	1.7 (8)	0.4 (14)
East	1957	11.4 (94)	10.5 (71)	17.9 (73)	44.9 (92)	25.4 (87)	34.8 (69)	1.2 (23)	11.2 (44)	10.3 (39)	2.4 (25)
West	1957	22.8 (94)	15.4 (100)	29.4 (96)	61.3 (77)	51.8 (87)	27.8 (56)	31.5 (33)	27.4 (28)	4.0 (19)	0.9 (42)
						INSECTS[1]					
East	1956	4.1 (100)	1.3 (40)	0.3 (14)	4.7 (60)	4.0 (43)	1.7 (30)	4.1 (69)	4.3 (59)	2.2 (46)	4.0 (71)
East	1957	0.1 (3)	0.8 (29)	0.3 (15)	0.4 (11)	0.2 (11)	1.3 (16)	2.3 (33)	2.0 (44)	1.2 (33)	13.5 (42)
West	1957	0.0 –	0.2 (18)	0.1 (11)	0.5 (9)	0.0 –	3.1 (33)	0.1 (5)	0.2 (12)	1.0 (33)	2.4 (36)

[1] Including Hydracarina.

ercentage occurrence of particular organisms ollowed the differences found in number per tomach quite closely.

Variation between years and stations

Use of the two most important groups of ood organisms, crustaceans and insects (inuding Hydracarina), by fish captured in hallow water was compared for different staions in 2 years. Crustacea were present in a igher percentage of stomachs in 1957 than 1956 (Table 13). Shiners from the West ation in 1957, however, contained the greatt number of Crustacea per stomach, fish om the East station in 1957 the second reatest, and fish from the East station in 956 the least. The 1956 East station fish d both the highest percentage occurrence d highest average number per stomach of sects, while the lowest quantities were in the 957 West station collections. These findings ggest that availability of the different food ganisms in the two areas and years influced the food contained in stomachs.

FOOD UTILIZATION AND FOOD ABUNDANCE

Zooplankton

Plankton samples taken at the times of the ne hauls were made with the net held 18 ches off the bottom and towed perpendicu to shore in the same manner as the seine uls. Simultaneous seine and plankton coltions were made at approximately 1-week intervals at the East station and at 2-week intervals at the West station.

Estimated combined numbers of Cladocera, Copepoda, and Ostracoda varied from 35,000 to 1,014,000 per liter (Table 14). Relative percentages of these groups varied considerably, with Cladocera the most abundant in 19 percent of the samples, Copepoda most abundant in 81 percent of samples, and Ostracoda always the least abundant. Total numbers and percentage compositions of these groups in fish stomachs from each collection date were calculated (Table 14). Although cladocerans were less abundant than copepods in the plankton, they were the most abundant zooplankton organisms in stomachs on 92 percent of the days. There was some tendency for spottail shiners to feed more heavily on Cladocera when these forms were more abundant. The correlation coefficient (r) between percentage composition in the plankton and in stomachs was $+0.43$ ($p < 0.05$). Correlations with Copepoda and Ostracoda were nonsignificant.

Since Cladocera were the most important crustacean food item, they were divided into five groups: *Chydorus, Daphnia, Diaphanosoma, Eurycercus*, and "others." Utilization and abundance of each group were correlated for young-of-the-year, yearling, and adult spottail shiners. Years and areas were kept separate, and in each case young-of-the-year shiners contained the five categories of Cladocera in order of their abundance (r signifi-

TABLE 14.—*Percentage compositions of three groups of Crustacea found in plankton tows and in spottail shiner stomachs, East and West stations, 1956–57, Lower Red Lake—expressed as percentages of total numbers of Cladocera, Copepoda, and Ostracoda in tows and stomachs on each sampling date*

Area and year	Date	Total number of Crustacea		Percentage composition					
		Tows (Thousands per liter)	Stomachs	Cladocera		Copepoda		Ostracoda	
				Tows	Stomachs	Tows	Stomachs	Tows	Stomachs
East station, 1956	June 23	691	1,120	24	100	75	0	0	0
	July 3	91	394	61	100	39	0	0	0
	14	85	7	4	14	96	0	0	86
	20	120	103	26	100	74	0	<1	0
	25	35	39	25	97	75	3	0	0
	Aug. 2	337	29	10	66	90	0	0	35
	7	102	46	27	94	73	0	0	7
	12	1,014	13	11	85	89	8	0	8
	16	52	325	20	14	80	86	0	0
	21	98	222	30	99	70	1	0	1
	Sept. 20	54	238	79	99	21	0	0	1
East station, 1957	June 6	509	69	10	93	90	0	0	7
	10	322	630	11	90	89	6	0	5
	21	814	386	58	99	42	1	<1	<1
	July 7	451	1,224	52	92	48	4	<1	4
	11	304	942	40	84	54	13	6	3
	25	94	684	32	100	59	0	9	0
	Aug. 8	489	1,040	31	100	70	0	0	0
	12	850	341	34	99	56	1	1	0
	16	67	39	10	31	90	69	0	0
West station, 1957	June 18	197	1,568	25	100	73	<1	0	<1
	30	933	565	68	100	32	0	1	0
	July 24	235	724	26	100	74	0	0	0
	Aug. 3	855	203	24	100	76	0	<1	0
	16	107	424	25	100	75	0	<1	<1
	24	160	1,810	19	100	81	0	0	<1

cant at 5- or 1-percent level, Table 15). Similar correlations of yearling and adult food items were not significant, but adults tended to contain Cladocera in reverse order of their abundance. Apparently large shiners selected large Cladocera.

Causes of differences between food selection and estimated abundance of Cladocera and Copepoda are not apparent from available data. It is possible, however, that the plankton organisms and fish were not distributed in the same manner, and the plankton sampler, at 18 inches from the bottom, was in an area of higher Copepoda concentrations than were the captured spottail shiners.

Bottom fauna

Bottom samples were taken at the South station in 1956 at depths of 2, 2½–3½, 3½–4½, 4½–6½, and 20–22 feet and in 1957 at the East station at 5–7½, 12–14, and 18–19½ feet. Stomachs from fish taken at the East station in 1956 and 1957 were divided into two groups according to the depth of capture (0–7 feet and 10–20 feet). Bottom fauna data from the South station were used to estimate bottom fauna at the East station in 1956 by making two adjustments: (1) the 2½- to 3½-foot samples were omitted because they were taken in a fringe of *Scirpus* sp., which was not present at the East station; and (2) the material from 4½–6½ feet was combined with that taken at 20–22 feet to estimate what was present at 10–20 feet at the East station because the 4½- to 6½-foot samples were taken at the edge of a steep drop-off to the 20-foot depth.

Number of organisms per 3 square feet in each group of bottom fauna was averaged for each season because number of samples was small, seasonal trends in abundance were not consistent between areas and years, and the most abundant groups on any date were essentially the same throughout the season. Total numbers of each group eaten by shiners dur-

TABLE 15.—*Correlation (r) between percentage composition of five groups of Cladocera in plankton and in spottail shiner stomachs taken on the same dates at the East and West stations, Lower Red Lake, 1956 and 1957*

Age group	East station		West station
	1956	1957	1957
0	+0.353*	+0.516**	+0.673**
I	−0.034	+0.143	+0.264
II and older	− 0.491	−0.037	−0.340

* Significant at the 5-percent level.
** Significant at the 1-percent level.

ABLE 16.—*Abundance of organisms in bottom samples and in spottail shiner stomachs at depths of 0–7 and 10–20 feet, all sampling days combined, South and East stations, Lower Red Lake, 1956 and 1957—expressed as average number per 3 square feet and total number in all stomachs*

Organism	1956 Average number per 3 square feet	1956 Total number in stomachs	1957 Average number per 3 square feet	1957 Total number in stomachs
	0–7 FEET			
alella	22.6	7	5.1	4
dracarina	0.2	62	0.5	70
hemeroptera	1.1	8	7.7	16
choptera	5.5	93	0.3	86
ironomidae larvae	31.2	325	64.8	537
ironomidae pupae	3.4	14	0.9	13
ironomidae adult	1.0	17	0.0	1
ratopogonidae	1.2	4	0.5	2
ecypoda (less than 4 mm)	151.8	20	100.1	5
	10–20 FEET			
alella	2.0	31	18.8	2
dracarina	6.2	61	3.0	1
hemeroptera	1.0	1	14.4	5
choptera	0.0	14	3.4	8
ronomidae larvae	24.2	53	281.4	188
ronomidae pupae	1.0	17	13.1	82
ronomidae adult	0.0	282	0.0	5
ecypoda (less than mm)	6.6	2	265.9	20

g the entire season (Table 16) were con- ered as the index of use.

Of 21 principal groups of organisms identi- d, only nine were represented by two or re specimens in all the stomachs taken at h depth ranges. They were *Hyalella*, Hydra- ina, Ephemeroptera, Trichoptera, Chiro- nidae larvae, Chironomidae pupae, Chiro- nidae adults, Ceratopogonidae larvae and pae, and Pelecypoda less than 4 millimeters g (Table 16). Percentage composition of h group in the bottom fauna was corre- d with its corresponding percentage com- ition in the stomach contents. Correlation fficients were: All nine groups included, $= +0.257$ (nonsignificant); Pelecypoda included, $r = +0.700$ ($p < 0.01$); Pele- oda not included and all Chironomidae bined (larvae + pupae + adults), $r =$ .931 ($p < 0.01$). If data from 1957 only used in the correlation between percentage position in the bottom samples and stom- for all nine groups, $r = +0.524$ ($p <$), and if Pelecypoda are not included, $+ 0.944$ ($p < 0.01$). Oligochaetes and ns larger than 4 millimeters were present ubstantial numbers but were not eaten.

further check on the relationships be- n abundance and use of food organisms was made by separating the family Chironomidae into six genera and correlating the percentage abundance of each genus in the bottom samples with that found in the stomachs. The correlation coefficient for the 1956 and 1957 collections combined was $+ 0.664$ ($p < 0.01$). *Tendipes* and *Pentaneura* were the most abundant genera in bottom samples and stomachs. Two families of Trichoptera (Leptoceridae and Hydropsychidae) were present in bottom samples and spottail shiner stomachs. Leptoceridae made up 90 percent of all Trichoptera in bottom samples and 74 percent of those identified in stomachs. These results indicate that the spottail shiner utilized only certain groups of bottom organisms and that these groups were taken in approximate proportion to their abundance.

ACKNOWLEDGMENTS

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Studies of the Normal Postmortem Changes in the Oyster, *Crassostrea gigas* (Thunberg)[1,2]

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Sacrificed oysters remained normal in gross appearance for 32 hours, then began to accumulate silt on the external surfaces; an odor of decomposition was first noticed at 48 hours; tactile response was normal for 48 hours, became progressively weaker and ceased by 104 hours. By 136 hours the adductor muscles of all oysters lost their attachment to the shell.

Microscopically, the digestive tubule area first showed postmortem changes with a progressive necrosis, followed by the gut, then the stomach. A multinucleate macrophage, probably characteristic of oyster decomposition, developed at approximately 72 hours postmortem. Gills and palps are relatively resistant to autolysis, while the gonadal region was found to be the most resistant of all oyster tissue to postmortem changes.

Introduction

A number of investigators (Mackin, 1951; Mackin, Korringa, and Hopkins, 1952; Stein, Denison, and Mackin, 1961; Sparks, 1962, 1963) have discussed the histopathological effects of various pathological organisms on oyster tissues. Shaw and Battle (1957) gave an excellent account of the normal histology of the digestive tract and associated tissues of the oyster, *C. virginica* (Gmelin). Gunter, Dawson, and Demoran (1957) studied the length of time necessary for total decomposition of sacrificed oysters and the rate of subsequent fouling of the empty shells, and attempted to determine the length of time the two valves remained attached by the hinge ligament. To date, however, no systematic study of the normal pattern and rate of postmortem decomposition in oysters has been published, so it is not possible to ascertain the length of time an oyster has been dead by either gross appearance or histological examination, nor

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can the effects on the tissues by the lethal agent be separated from the normal process of autolysis. With the recent emphasis on histopathological studies of oyster mortalities it has become increasingly important to be able to differentiate the effects of pathogens on oyster tissue from the normal decomposition of the oyster after death has occurred.

There are unquestionably a number of factors that influence the rate at which autolysis of an individual dead oyster proceeds. These include, but are probably not confined to, the temperature of the water, dissolved oxygen concentration, bacterial flora of the water and the oyster, fatness and gonadal condition of the oyster, and the variations in the physiology of the individual oyster. Despite similar variations, it has been demonstrated in other species, particularly in man, that postmortem changes occur in a regular and irreversible pattern and at a relatively constant rate from one individual to another when known factors causing variation in the rate and pattern are considered.

Death in the oyster is difficult to define since somatic death, or death of the entire organism, comes only after necrosis, or cell death, of large areas of the oyster's body has occurred. While this same phenomenon occurs in the vertebrate (for example, nerve cells die within minutes after the termination of blood circulation while cartilage cells live for several days), death of the individual occurs within a very few minutes after heartbeat stops, as anoxia of vital organs such as the central nervous system leads to irreversible changes. As is well known, cilia on the gills and mantle epithelium of the oyster continue to beat for several days after massive necrosis and autolysis of much of the rest of the body has occurred.

In attempting to ascertain the normal postmortem changes in oyster tissue, it would be preferable for the oyster to die with a minimum of histological involvement. Numerous methods of killing the oysters so that "normal" changes after death could be studied were considered before finally deciding to sacrifice them by surgically severing the heart and to then study the changes in the tissues at various intervals after death to determine the pattern and rate of necrosis. Although it is realized that this, technically, is not a normal death but death resulting from mechanical damage, it was assumed that the subsequent changes postmortem from such deaths would be more nearly normal than from any other means, since the following advantages were obtained:

(1) The "death time" or at least the time at which the damage occurred was accurately known.

(2) Tissue away from the source was not damaged.

(3) There was little possibility for tissue repair and survival from such radical treatment.

Materials and Methods

Three laboratory experiments and one field experiment were set up under similar conditions as follows:

In experiments 1 and 2, 24 oysters were collected from commercial beds in Oyster Bay, Washington and taken to the College of Fisheries. The following morning 12 of these oysters were opened, similarly to the method used by Bang (1961), and the heart severed. These sacrificed oysters were designated as "dead" oysters. A dead oyster and a live oyster were placed in each of 12 aquarium jars containing aerated, noncirculating sea water collected from the same location as the oysters. The jars were placed in a temperature-controlled water bath and the temperature in the jars maintained at 14–16°C.

Immediately after sacrificing the experimental oysters, a "dead" oyster and its accompanying control were fixed in Zenker's Fixative and the same procedure was followed at varying time intervals. The time intervals, postmortem, for fixation in the first experiment were 1, 4, 8, 16, 24, 32, 40, 56, 64, and 72 hours after sacrifice and in the second experiment were at 8-hour intervals through 96 hours postmortem.

The third experiment was similar to the first two except that 1 control and 2 dead oysters were placed in each jar and fixed together at 8-hour intervals from 72 hours after the initiation of the experiment to 144 hours postmortem.

In an attempt to relate the laboratory results with the pattern and rate of decomposition of oysters under normal conditions, a field investigation was conducted in which 74 oysters were sacrificed as described for the laboratory experiments. The valves were then fastened in place by a rubber band with an opening created between the valves of each experimental oyster to allow free water circulation. These experimental oysters were then placed, along with a like number of unopened oysters, in a basket suspended from floats. Two sacrificed and 2 control oysters were fixed at 8-hour intervals from 8 hours postmortem until 144 hours postmortem. The principle difference between the field and laboratory experiments was that water temperatures in the field could not be controlled and varied from 15.6°C to 18.1°C.

Observations from gross examination of the live and dead oysters at the time of fixation included odor, ciliary action (as seen with a stereoscopic microscope), response of the mantle to tactile stimulus, and gross appearance of the tissue.

All oysters from each experiment were dehydrated and blocked in a group. Oysters from each experiment were stained simultaneously in Harris hematoxylin and eosin in two groups, with the experimental and control specimens for each time interval stained together, insuring identical treatment for all sets and virtually identical treatment for the entire lot. Differences in staining reaction would thus reflect changes in the histology of the oyster rather than differences in staining technique.

Results and Discussion

GROSS APPEARANCES

Sacrificed oysters were normal in appearance until 32 hours, when mucous containing silt began to accumulate on the outside of the mantle. This condition was noticeable for the rest of the experiment. An odor of decomposition was first noticed at 48 hours and became progressively stronger as the study continued, becoming more pronounced at 88 hours and putrid at 112 hours. Tactile response was normal for the first 48 hours, becoming weaker between 56 and 96 hours, and ceasing by 104 hours. During this time, the villi on the mantle gradually became more contracted and were invariably contracted after 96 hours. The texture of the body gradually changed in appearance after sacrifice, appearing normal through 88 hours but becoming more watery from 96 hours on. After 128 hours most oysters were so advanced in decomposition that the various organs of the body could no longer be distinguished at gross examination, with a considerable portion of the 144-hour specimen lost. The adductor muscle lost its attachment in one specimen after 104 hours and in all oysters from 136 hours through 144 hours.

MICROSCOPIC EXAMINATION

Digestive Tubules

The first tissues to be affected in postmortem autolysis are in the area of the digestive tubules (Fig. 1). As early as 24 hours postmortem in the laboratory experiments the Leydig cells between the inner tubules begin to lose their nuclei and, as karyolysis proceeds, the cytoplasm fades in staining intensity and is lost. As autolysis continues (Fig. 2), the epithelium in the smaller ducts begins to fragment and becomes separated from the

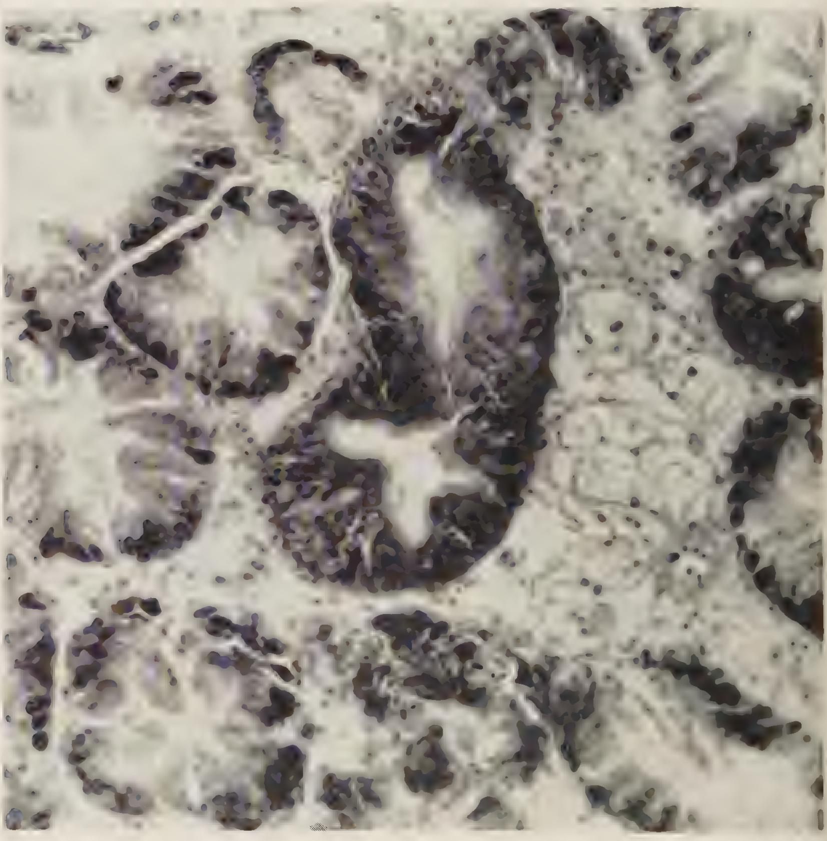

FIG. 1. Normal digestive tubules and Leydig cells. 366 ×.

underlying basement membrane. This may begin as early as 24 hours postmortem, but the separation, or sloughing, may not occur until between 32 and 40 hours and is occasionally delayed until 48 hours postmortem. As decomposition continues, autolysis spreads to the peripheral tubules and the changes become more marked with the Leydig cells disappearing, leaving tissue debris between the basement membrane of the tubules, and the sloughing and fragmentation of the tubules becomes more marked. This stage is usually present at 72 hours, but may be somewhat delayed. At about this time the larger tubules begin to fragment and the epithelium separates from the basement membrane. In some instances some of the tubule epithelial linings are lost, leaving the basement membranes with

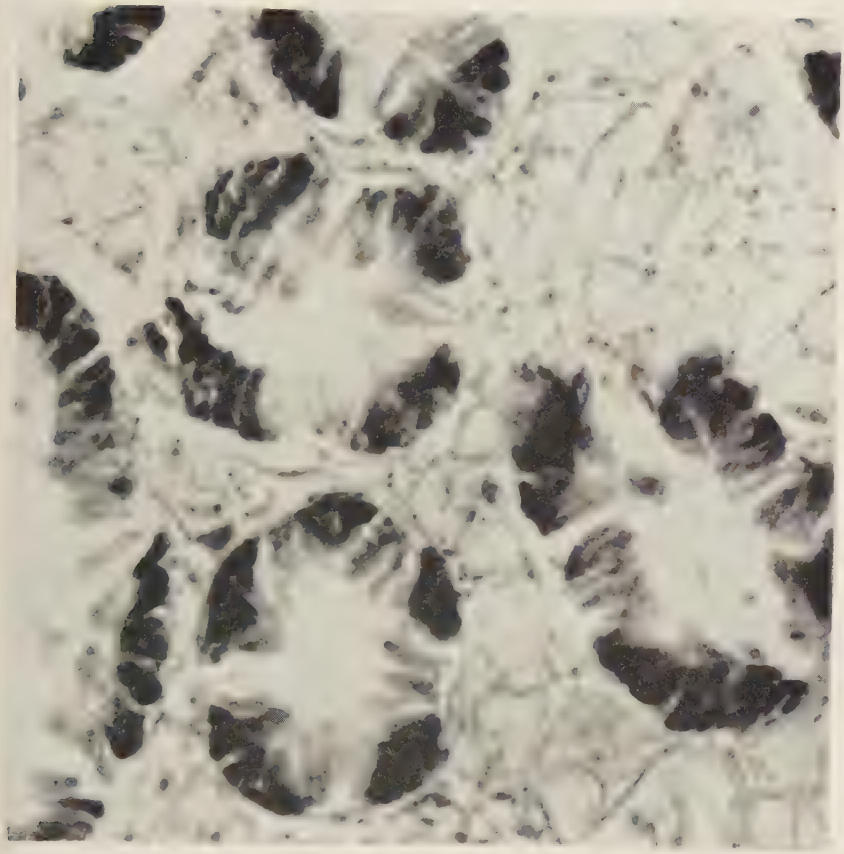

FIG. 2. Digestive tubules and Leydig tissues 48 hours post-mortem. 366 ×. Note fragmentation and sloughing of epithelium and karyolysis of nuclei in Leydig cells.

empty spaces where the epithelial linings were originally found (Fig. 3). Most of the basement membranes are eventually lost, leaving only scattered fragmenting epithelial linings of tubules. This condition is reached between 96 and 144 hours postmortem (Fig. 4).

In the field experiment the general pattern and rate of autolysis was quite similar to that of the laboratory experiments, but began earlier and did not proceed quite so far. Typical necrosis first appeared at 18 hours, almost certainly because of a temperature elevation of approximately 3 degrees. By 24 hours considerable necrosis of Leydig cells had occurred and fragmentation of the epithelial lining had begun. Subsequent periods

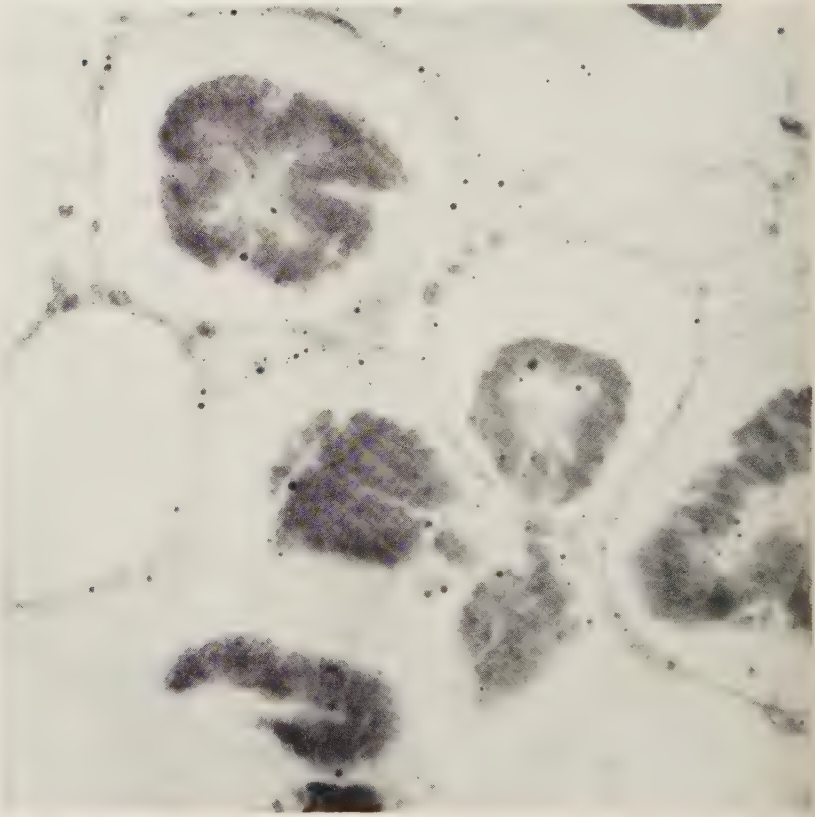

FIG. 3. Digestive tubules and Leydig tissues 104 hours post-mortem. 366 ×. Note complete separation of epithelium from basement membrane and complete loss of nuclei in Leydig cells.

post-mortem demonstrated a progressive necrosis of epithelium with extensive fragmentation occurring as early as 40 hours and sloughing of the epithelium also occurred as early as 32 hours. These phenomena were not observed in the laboratory study until 72 hours. During the field experiment temperatures ranged from 16.2° to 17.8°C, somewhat higher than the 14–16°C of the laboratory experiments. The loss of the basement membranes of tubules occurred at approximately the same time, 96 to 144 hours, as in the laboratory studies, but was not so pronounced as in the laboratory investigation, even in the later stages.

It has been noted that under unfavorable conditions or with poor

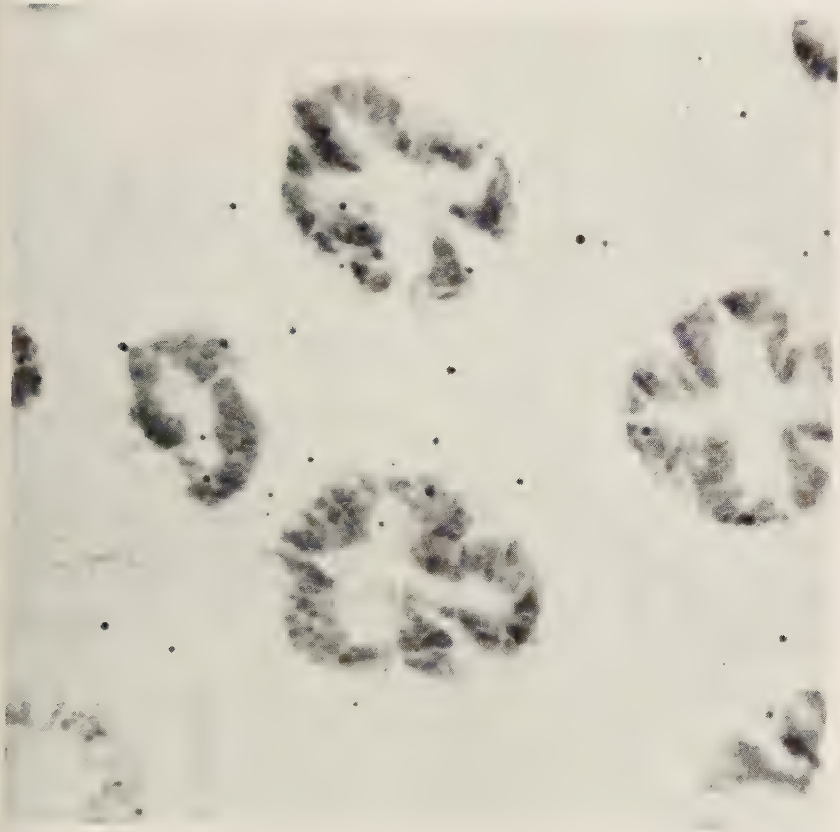

FIG. 4. Digestive tubules and Leydig tissues 128 hours post-mortem. 366 ×. Note fading of epithelium and complete autolysis of Leydig tissue.

fixation, the changes described begin in what were considered to be normal oysters. Autolysis may proceed as far as karyolysis of the Leydig cells, sloughing of the epithelial lining, and initial fragmentation of the epithelium of the deeper tubules (i.e., to approximately the condition of 72 hours normal post-mortem). The digestive tubules have been found to be the most sensitive indicator of unfavorable conditions, poor fixation, or postmortem change.

Intestine

In the laboratory experiments the gut appeared normal (Fig. 5) hrough at least 40 hours in all studies, but at 48 hours, in all experimental oysters, postmortem changes were detectable. The epithelium was more densely basophilic, the nuclei becoming pycnotic with crumbling and concentration of the chromatin (Fig. 6). Although typical of 48 hours postmortem, pycnosis of the gut may be delayed through 72 hours. Typically,

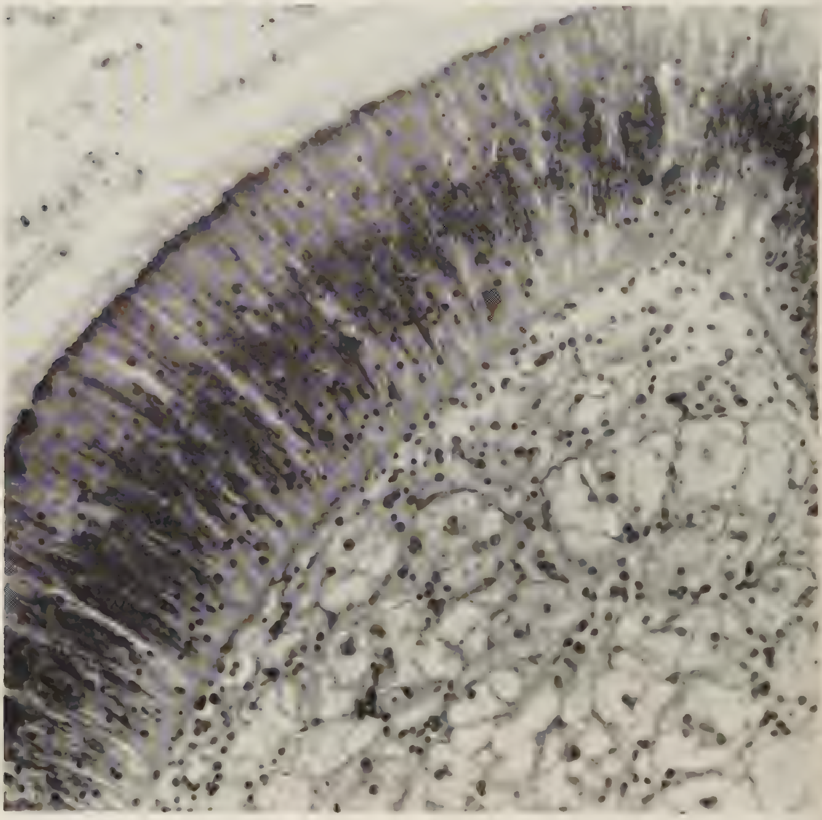

FIG. 5. Normal gut. 366 ×.

the epithelium begins to separate from the basement membrane (Fig. 7) by 64 hours post-mortem, but sloughing has been observed to start as early as 48 hours or to be delayed through 72 hours, or, in one example, as long as 96 hours. Virtually all oysters, however, fixed after 64 hours exhibited the phenomenon of sloughing of the gut epithelium.

At about 88 to 104 hours post-mortem (Fig. 8) but sometimes delayed, the gut walls exhibit the phenomenon of coagulation necrosis. The epithelium begins to lose its basophilic staining reaction, fading to a light pink, with the nuclei becoming karyolytic. The cell membranes are lost. The cells are fragmenting, the secretory granules are becoming scattered, and they stain less intensely. The greater curvature of gut seems to exhibit these features before the lesser curvature and typhlosole do. Bacteria often become conspicuous in the lumen and along the edge of the epithelium. In most instances the cilia began to slough. At about this time the gut becomes greatly distended, there is a marked leucocytic infiltration just beneath the basement membrane and the underlying Leydig cells undergo karyolysis.

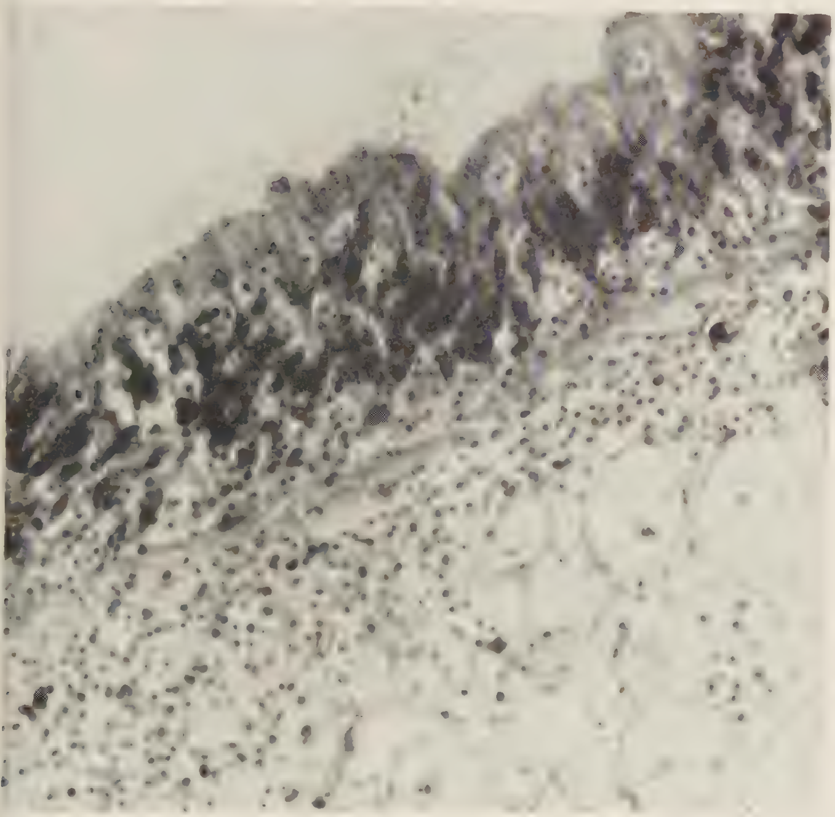

FIG. 6. Gut 56 hours post-mortem. 366 ×. Note disorganization of epithelium and leucocytic infiltration beneath basement membrane.

As observed in the digestive tubules, postmortem changes in the gut in the field experiments were initiated earlier, begining as early as 18 hours with some sloughing of cilia, slight fragmentation of the epithelium, necrosis of the Leydig cells beneath the gut with accompanying leucocytic infiltration. These postmortem changes continued and intensified in subsequent oysters in the series and at 56 hours the first sloughing of the intestinal epithelium was observed. This phenomenon was not observed in another oyster until 96 hours and was typical of the postmortem changes in the gut from that time on, although in two examples, at 104 hours and 112 hours, the epithelium retained its attachment to the basement membrane while the other typical postmortem changes occurred. The emigration of leucocytes into the area beneath the gut and stomach

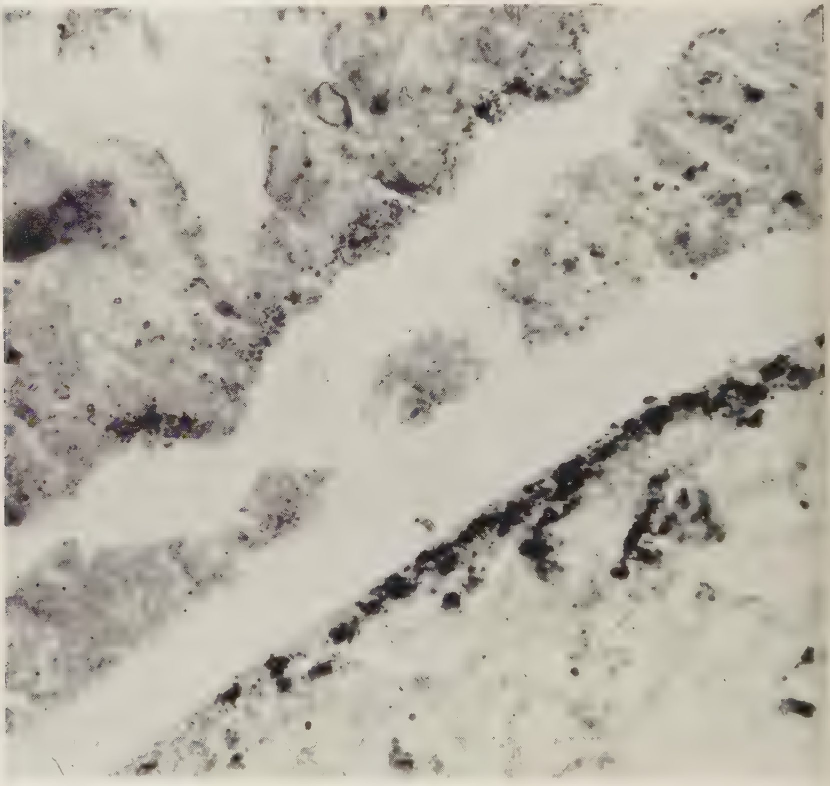

FIG. 7. Gut 104 post-mortem. 366 × Note separation of epithelium from basement membrane.

as the Leydig cells undergo necrosis was particularly conspicous and is apparently diagnostic of the postmortem breakdown of the digestive system.

It is possible that the gut is a better tissue for determination of death time of the oyster than the tubule area because it is less sensitive to poor environmental conditions and the onset and progression of decomposition appear to be more consistent with the time elapsed after death.

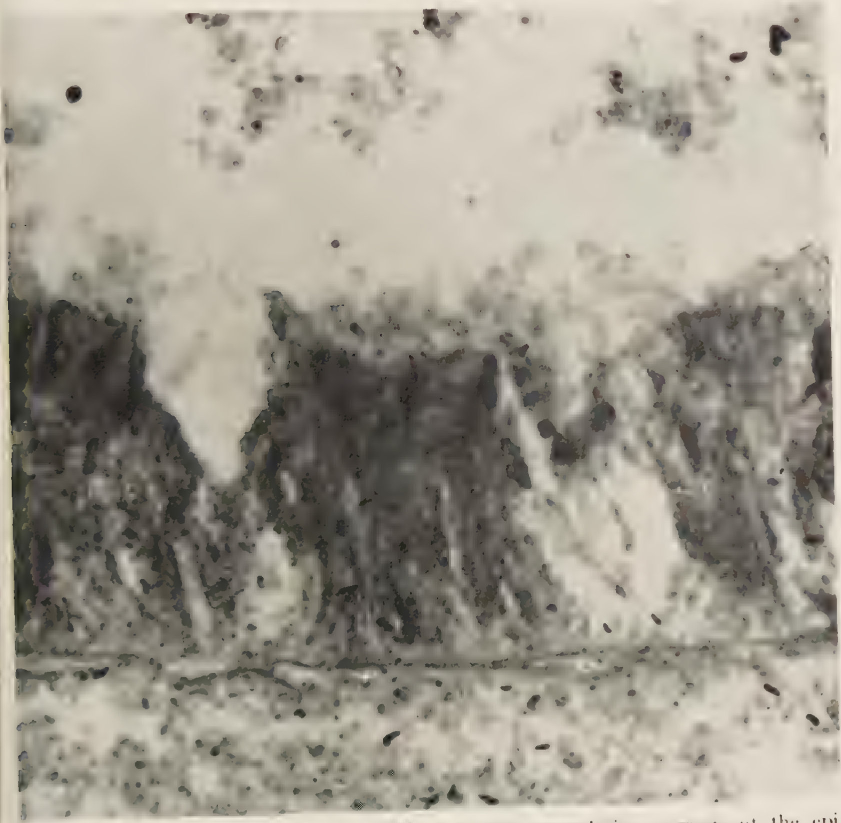

Fig. 8. Gut 88 hours post-mortem. 566 ×. Note coagulation necrosis of the epithelium.

Stomach

Postmortem change in the stomach follows the same pattern as the gut, but usually begins considerably later than the gut. In one sacrificed oyster at 48 hours post-mortem there was epithelial sloughing and karyolysis of the underlying Leydig cells, but the appearance of the sloughed epithelium was normal. All other dead oysters fixed prior to 64 hours post-mortem exhibited a normal histology in the stomach. Beginning at 64 hours, however, the epithelium progressively becomes faded, loses its basophilic staining properties, fragments, and, in most cases, pulls away from the basement membrane. There is often a leucocytic infiltration beneath the basement membrane and the underlying Leydig cells undergo karyolysis. Beginning at approximately 112 hours, portions of the epithelium disappear, but there is a great deal of variation in the time at which this occurs, with the epithelium exhibiting coagulation necrosis, though very lightly stained through 144 hours. The Leydig cells beneath the gut begin to lose their nuclei and cytoplasm at about 64 hours post-mortem and this necrosis spreads outward as decomposition progresses. The decomposition of the stomach in the field experiment again followed about the same pattern as in the laboratory, but appears to be initiated somewhat earlier.

Mantle

Understanding of the postmortem changes in the mantle is complicated by the changes in the mantle epithelium and connective tissue associated with the gonadal cycle of the oyster. There is a tendency for the epithelium to become pycnotic, usually at about 48 hours, then, at approximately 72 hours, the epithelium begins to fade. The nuclei become shadowlike and the cytoplasm no longer stains (Fig. 10). The epithelium on the free edge of the mantle, however, remains deeply basophilic in staining reaction for a long period (Fig. 9), beginning to fade only after 96 hours or more post-mortem. Sloughing of portions of the mantle epithelium may begin as early as 48 hours, but may remain intact for as long as 72 hours. Sloughing of epithelium from the edge of the mantle (Fig. 10) does not ordinarly occur before 96 hours and may be delayed for a slightly longer period.

The mantle Leydig area remains relatively normal for approximately 24 to 32 hours and then becomes vacuolated by the loss of Leydig cells in scattered areas. At this time a general leucocyte infiltration may develop. The Leydig cell areas begin to fade at about 72 hours and lose their nuclei and cytoplasm in a progressive pattern from the periphery of the mantle inward (Fig. 10). There is a great deal of variation in the time of onset of the general necrosis, with most of the mantle remaining fairly normal in appearance for more than 100 hours.

Beginning as early as 32 hours post-mortem, but usually at 72 hours, numerous peculiar multinucleate cells appear in the mantle Leydig areas of most of the dead oysters, particularly near the periphery (Figs. 10, 11, and 12). The cells are considerably larger than the typical leucocytes and contain as many as a dozen or more deeply staining nuclei surrounded by faint cell outlines. These cells are unlike any cells previously seen in normal oysters and were first thought to be microorganisms. It was noted, however, that they appeared only after a relatively long period post mortem and, while they were present in about half the dead oysters fixed between 64 to 104 hours and in 9 of 10 experimental oysters in the 112 to 144 hour postmortem stages, they were not found in any of the control oysters.

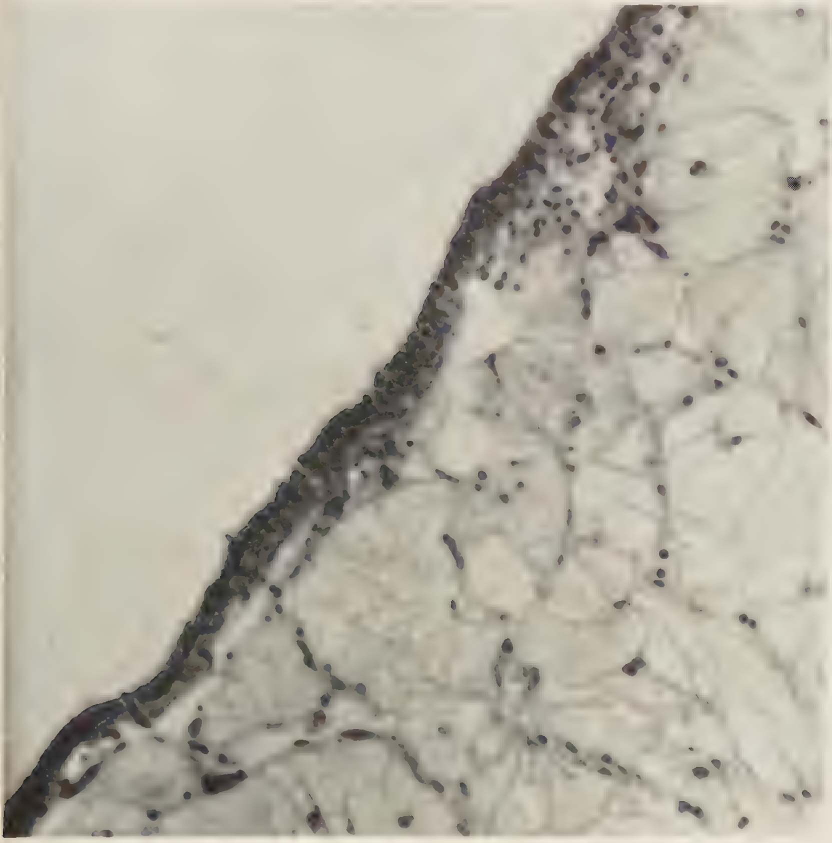

FIG. 9. Normal mantle epithelium and connective tissue. 366 ×.

These data leave three alternatives as to the nature of these cells: (1) They are, as was originally thought, a multinucleated microorganism present in the oyster population from which the oysters for the experiment were taken and by chance the oysters selected for the latter stages of the experiment were the only infected oysters or they developed to a recognizable stage only after a relatively long period after the oysters were sacrificed. (2) These cells are saprophytes which invade the tissue at advanced stages of decomposition. (3) They represent a type of oyster cell which develops during the decomposition of the oyster. From study of the slides and data of these experiments, it is the opinion of the authors

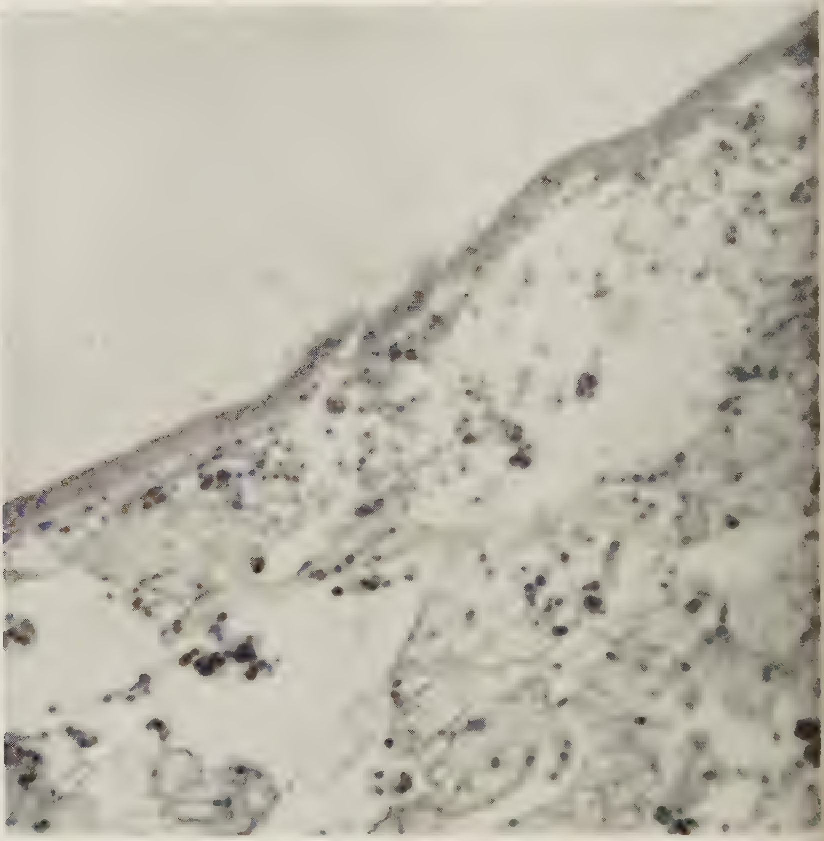

FIG. 10. Mantle area 136 hours post-mortem. 366 ×. Note faded epithelium, vacuolated area of connective tissue, and multinucleate macrophages.

that the latter is the correct interpretation. It is thought that these "giant cells" were uninucleate macrophages which have engulfed large numbers of necrotic leucocytes and, perhaps, nuclei and cell debris of Leydig

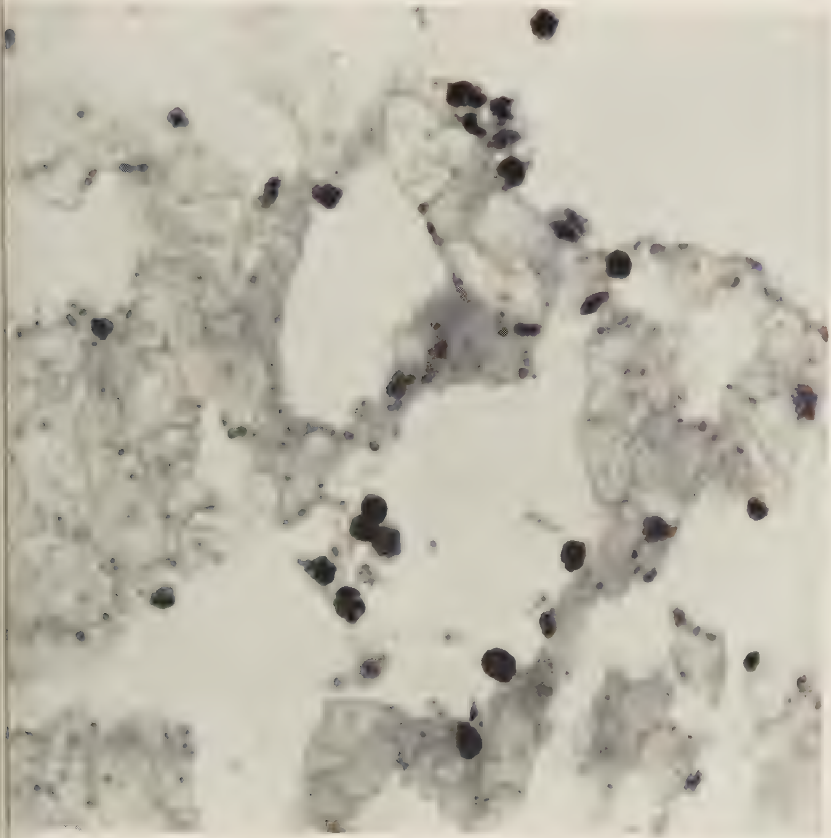

FIG. 11. Leydig cells of mantle area 40 hours post-mortem. 366 ×. Note numerous ultinucleate macrophages, many of which contain phagocytosed sperm.

lls. The pycnotic condition of these phagocytosed cells cause them to ppear unlike oyster cells.

The multinucleate macrophages, or "giant cells," were present in many the field experimental oysters but in none of the normal oysters. These lls were found earlier in the field than the laboratory studies, beginning 24 hours and occurring as late as 136 hours, but were not so numerous the dead oysters from this experiment, nor occurring in as many of them, as in the laboratory studies. Further indication that these cells are products of decomposition of the oyster was provided by the presence of numerous phagocytosed sperm in giant cells from a male experimental oyster (Figs. 11 and 12).

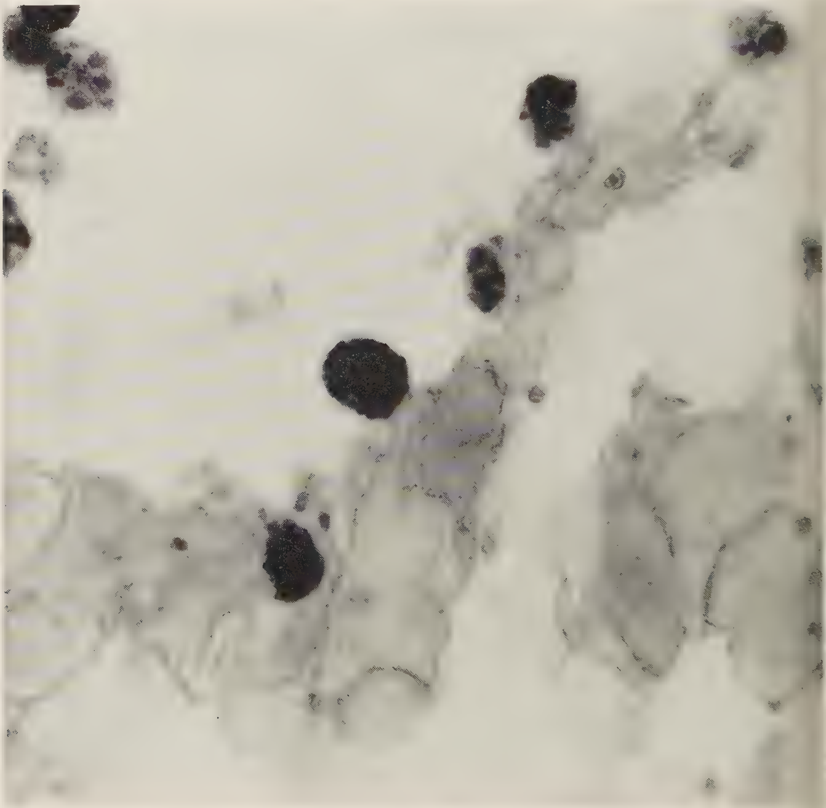

FIG. 12. Higher magnification of multinucleate macrophages in Fig. 11. 915 ×.

The autolysis of the mantle followed the same pattern and essentially the same rate, but somewhat accelerated, in the field as in the laboratory, beginning at 24 hours with loss of Leydig cells and shrinkage of the nerve in the tips of the mantle. Sloughing of the mantle epithelium began as early as 56 hours and became progressively greater through 104 hours. After 104 hours much of the entire mantle, especially over the gonadal areas, was sloughed, with most of the remaining mantle usually completely autolyzed, with no cells being recognizable.

Gills and Palps

The gills and palps are relatively resistant to postmortem change with no discernible changes occurring until 72 hours postmortem with the pithelium staining much more basophilic and, by 72 to 96 hours, becoming

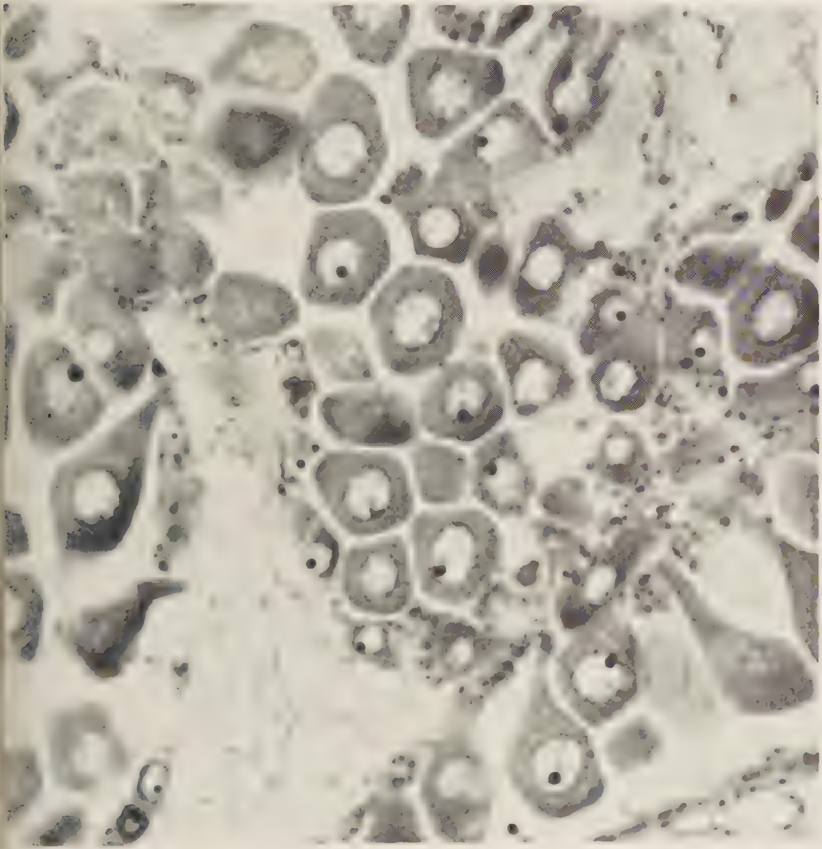

FIG. 13. Normal ova. 366 ×.

ycnotic. By 96 hours the epithelium of some oysters has begun to slough. he Leydig cell tissue begins to break down and often contains numerous iant cells. Usually by 120 hours the epithelium begins to stain less innsely and by 136 hours post-mortem the gills may be fragmenting, aving only scattered portions of the gill bars. In the field no appreciable ecrosis was observed until 104 hours after sacrifice at which time pycnotic uclei and fragmentation of the epithelium was evident in most specimens.

Gonadal Region

The gonadal region of the oyster is the last tissue to undergo necrosis; often the ova or sperm appear appear relatively normal (Figs. 13 and 15) after all other tissues have undergone extensive autolysis. Again, differences in the gonad because of the normal gonadal cycle must be considered in evaluating the amount of change due to decomposition, particularly in regard to leucocytic infiltration and phagocytosis of the sex products.

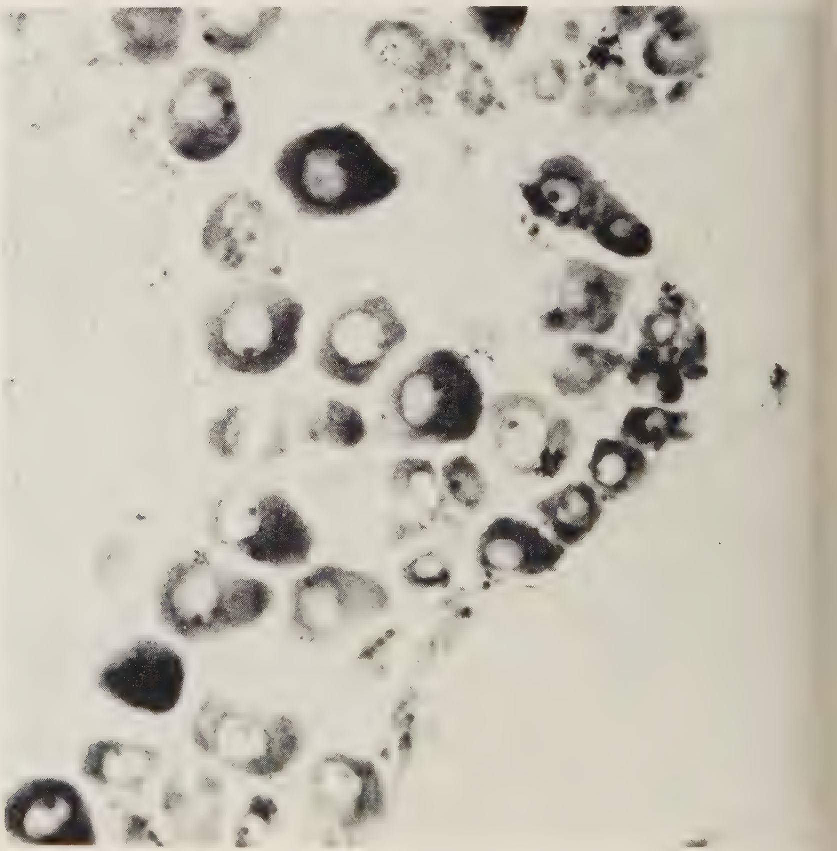

FIG. 14. Ova 128 hours post-mortem. 366 ×. Note relatively little decomposition of eggs, while Leydig tissue has undergone almost complete autolysis.

The gonads of all oysters were normal at least through 48 hours post-mortem in the laboratory. As early as 56 hours, the gonadal ducts of some ysters appeared to be slightly pycnotic, while this condition may be elayed through 72 hours in other oysters. Leucocytic infiltration of the onadal ducts may appear as early as 56 hours, but some oysters s late as 144 hours post-mortem do not exhibit this phenomenon. Because f the phenomenon of phagocytosis of sex products in resorbtion and e apparent lack of a consistent pattern in the onset and amount of ucocytic infiltration in the gonadal ducts, apparently no significance postmortem change can be attributed to this condition.

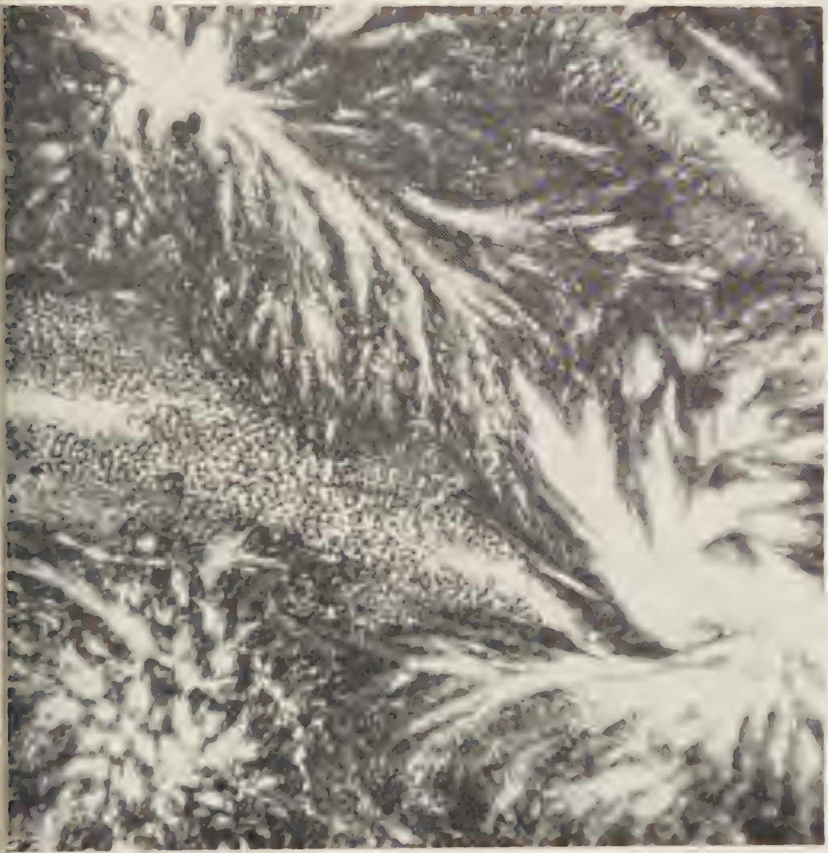

FIG. 15. Normal sperm. 366 ×.

Cilia of the gonadal duct epithelium may begin to slough away by 72 ours post-mortem, though this does not usually occur until 88 hours.

when the epithelium itself may also begin to slough from the basement membrane and to lose its staining intensity.

The Leydig cells between gonadal follicles are unaffected for a considerable period, with the first observed breakdown at 104 hours after sacrifice. "Dead" oysters with predominantly normal Leydig cells in the gonadal area as late as 136 hours were observed, but typical karyolysis of these cells occurs, usually starting at approximately 112 hours. The sex products themselves are extremely resistant to autolysis, with the first signs of necrosis observed at 88 hours post-mortem with disentegration of some ova observed. Generally, however, ova (Fig. 14) and sperm (Fig. 16)

FIG. 16. Sperm 144 hours post-mortem. 366 ×. Note karyolysis of sperm, and large numbers of leucocytes in this area.

undergoing phagocytoses, fragmentation, loss of nuclei and scattering ough the surrounding tissues from 96 hours on, though normal-appearing nads have been observed as late as 136 hours post-mortem. As break- wn of the gonads proceeds, large concentrations of bacteria typically velop in the area.

Postmortem changes appeared to have been initiated much earlier in gonads of oysters in the field experiment than was observed in the oratory. Some gravid females appeared to contain necrotic ova as early 32 hours, while karyolysis and fragmentation of ova was typical after hours post-mortem. This experiment was conducted during a post- wning period of resorbtion of sex products and the ova may have been dergoing changes prior to initiation of the experiment. However, the ads of control oysters appeared normal and leucocytic infiltration of gonads in the typical resorbtion pattern was not common. Postmortem nges of male gonads was not observed until 136 hours, at which time y exhibited the typical pattern observed in the laboratory studies.

Recapitulation

rossly, oysters appeared normal for 32 hours after sacrifice at which e excessive amounts of mucous accumulated on the outside of the y. An odor of decomposition was first noted at 48 hours and became e pronounced with further time post-mortem. Tactile response was mal for 48 hours, gradually became weaker and ceased by 104 hours. 136 hours post-mortem, all sacrificed oysters had lost muscular chment to the shell.

he *digestive tubule area* is the first to show postmortem change, as y as 24 hours, with a progressive karyolysis of the surrounding Leydig s, followed by sloughing and fragmentation of the epithelial lining, ally by 72 hours post-mortem. Between 96 and 144 hours the base- t membranes disappear, leaving only scattered fragmentary epithelial ngs. The digestive tubules are the most sensitive indicator of unfavorable ditions, poor fixation, or postmortem change.

he *gut* does not begin to break down until approximately 48 hours is characterized by a progressive pattern of pycnosis followed by olysis, coagulation, and necrotic fragmentation of the epithelium separation from the basement membrane, with accompanying dis- ion of the gut, between 64 and 104 hours post-mortem. The gut is bably the best tissue for determination of death time of the oyster, use it is less sensitive to poor environmental conditions and the onset and progression of decomposition appear to be more consistent with the time elapsed after death.

The *stomach* follows approximately the same progression in decomposition as the intestine, but beginning somewhat later than the gut.

The *mantle* typically begins to break down after about 24 hours, characterized by, first, pycnosis of the epithelium, then fading and sloughing which usually begins after 96 hours.

There is a *multinucleate macrophage type of cell,* not previously recognized in oysters, which is designated herein as a "giant cell" that develops usually at 72 hours in the Leydig cell areas of the mantle from the ingestion of numerous necrotic leucocytes and other cells and probably represents a phenomenon characteristic of postmortem decomposition of the oyster. Decomposition of the mantle develops from the periphery inward.

The *gills and palps* are relatively resistant to autolysis with no changes occurring before 72 hours post-mortem. They then become pycnotic and begin to slough the epithelium. By 120 hours the epithelium stains less intensely and the gills begin to fragment by 136 hours after death.

The *gonadal region* is the most resistant of all oyster tissue to autolysis with no necrosis prior to 48 hours. An apparent pycnosis occurs in the gonadal ducts beginning between 56 and 72 hours. Karyolysis and sloughing of gonadal duct epithelium may begin by 88 hours. The Leydig cells of the gonadal region become karyolytic, usually at about 112 hours. Sex products are extremely resistant to autolysis, being delayed until at least 88 hours and characterized, in the ova, by fading, loss of nuclei, fragmentation and scattering, and by the development of large colonies of bacteria.

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The authors are deeply indebted to Mr. Raymond Simon of the College of Fisheries, University of Washington for taking the numerous photomicrographs used in this study. Mr. Ian Ellis and Mrs. Daphne Pereyra, formerly of the College of Fisheries, aided in setting up and processing the oysters from the first two laboratory experiments.

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Total integrated mass transports and actual circulation in the eastern South Pacific Ocean[1]

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(Manuscript received June 5, 1963)

ABSTRACT

Using wind stress data computed by Hidaka, the total integrated mass transports have been calculated for the eastern South Pacific Ocean during the four seasons. They are compared with the circulation derived from geostrophic calculations and directly wind-induced currents in the region off Peru. Although total integrated mass transports may have considerable theoretical value, it is shown that in large parts of the eastern South Pacific Ocean they do not even qualitatively agree with major currents in the surface layer. Therefore a discussion and interpretation of total integrated mass transports seems advisable only if additional evidence about the vertical structure of the circulation is added.

1. Introduction

The total integrated mass transport M has received much attention in theories of oceanic circulation, bacause its components can be represented as the derivatives of a mass transport function ψ, $M^x=-\partial\psi/\partial y$ and $M^y=\partial\psi/\partial x$, which has to satisfy the differential equation $\partial^2\psi/\partial x^2+\partial^2\psi/\partial y^2=0$. The use of this function transforms the three-dimensional ocean circulation into a two-dimensional field, thus losing all information on the vertical structure of the circulation. If it is assumed that time dependence, inertia terms and lateral stresses can be neglected, and that vertical shear is given by the wind stress at the sea surface, and vanishes at the bottom, Sverdrup (1947) has shown that the mass transport function can be calculated by integrating the equation

$$\beta\frac{\partial\psi}{\partial x}=\frac{\partial\tau^y}{\partial x}-\frac{\partial\tau^x}{\partial y} \qquad (1)$$

where τ is the vector of the wind stress at the sea surface, $\beta=\partial f/\partial y$ the variation of the Coriolis parameter with latitude, and the x-axis points east. As a consequence of the vertical integrations, this equation is independent from specifications about the nature of variations of vertical shear with depth. As pointed out by Stommel (1958, p. 156), equation (1) expresses the condition under which the divergence of the Ekman wind drift is compensated for by the divergence of the geostrophic flow. Due to the effect of stratification, ocean currents are usually of limited depth and often accompanied by subsurface flow in different or even opposite direction. Consequently it seems advisable to investigate the extent to which total integrated mass transports compare with major currents in the surface layer or to which conclusions can be drawn about the circulation in deeper layers, if information about the circulation in the surface layer is available.

2. Seasonal charts of the total integrated mass transport.

Hidaka (1958) published values of the average wind stress distribution at the surface of the oceans for the four seasons based on five degree square averages of wind observations. These data have been used to calculate ψ according to equation (1)

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[1] Contribution from the Scripps Institution of Oceanography, University of California, San Diego.

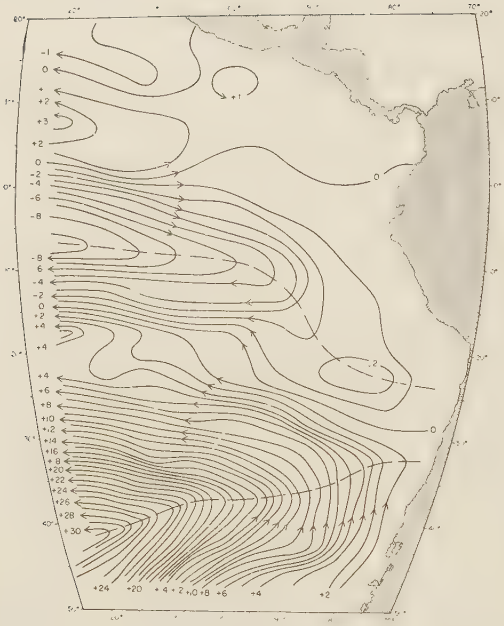

Fig. 1. Total integrated mass transports in million tons/sec in the eastern South Pacific Ocean in the season December to February.

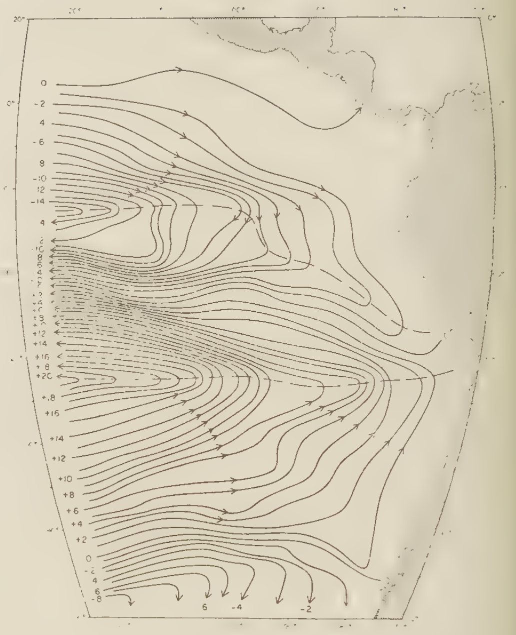

Fig. 3. Total integrated mass transports in million tons/sec in the eastern South Pacific Ocean in the season June to August.

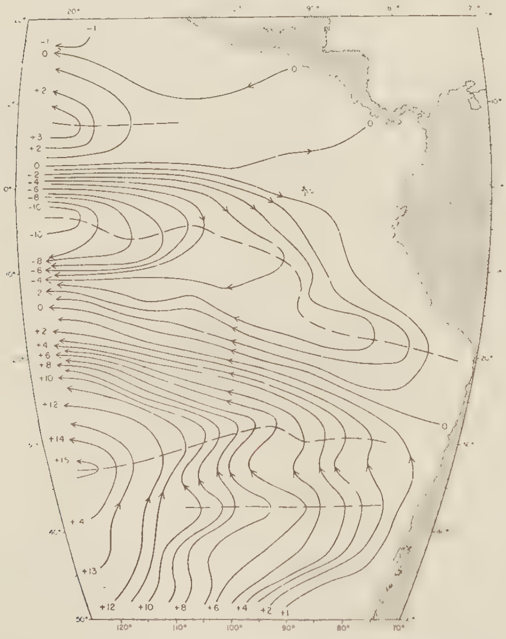

Fig. 2. Total integrated mass transports in million tons/sec in the eastern South Pacific Ocean in the season March to May.

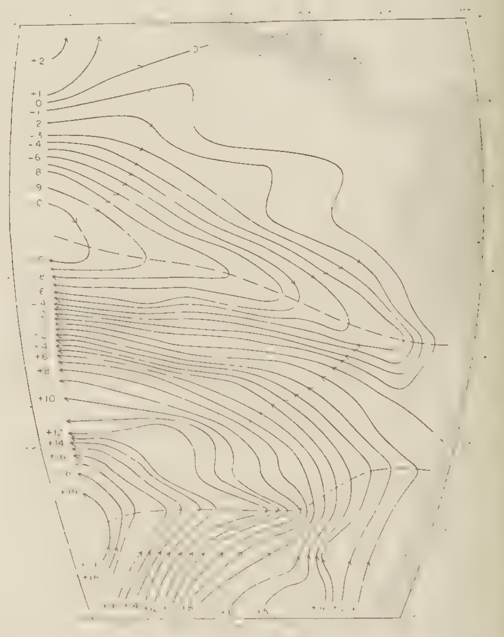

Fig. 4. Total integrated mass transports in million tons/sec in the eastern South Pacific Ocean in the season September to November.

for the eastern part of the South Pacific Ocean, starting the integration at the coast of South America. Figs. 1–4 show the mass transport function during the four seasons; the unit is million tons/sec.

The general features of the mass transport function are very similar during all seasons, the differences being variations in the intensity of the circulation and shifts in the positions of the main features. In the southern part of the region the circulation is anticyclonic. The center of the anticyclone shifts from 42°S in summer (December-February) to 23°S in winter (June-August) at 120°W. The intensity of this anticyclonic flow seems to be strongest in summer with 30 million tons/sec and weakest in autumn with only 15 million tons/sec. This variation of the intensity of the anticyclonic circulation could, however, be due to a zonal shift of its center. In all seasons except winter (June-August) the anticyclone extends to the south of 50°S, but in winter a cyclonic flow with components to the south is found south of 43°S.

On both sides of the equator the flow is to the east. It varies only slightly between 12 and 15 million tons/sec at 120°W. During all seasons a transport of water from the northern to the southern hemisphere across the equator takes place in the eastern tropical Pacific Ocean. South of the equator the circulation is cyclonic, the center of the cyclone varying only slightly between 3°S and 7°S near 120°W. The boundary between the flow to the east and that to the west moves progressively south when approaching the coast of South America so that the cyclonic circulation reaches far into the corner formed by the coast of South America near 20°S. This causes a total mass transport to the southeast off the coast of Peru.

A comparison of these maps of the total mass transports with the major ocean currents in the surface layer shows very little agreement. Therefore it must be concluded that movements in subsurface layers contribute similar amounts to the total mass transports as do the well known surface currents. In the equatorial zone the Equatorial Countercurrent and the Equatorial Undercurrent are flowing east transporting about 20 and 30 million tons/sec respectively, and parts of the South Equatorial Current are flowing west. The maps of the total mass transport indicate a flow to the east of 12–15 million tons/sec in this zone, thus leaving about 35 million tons/sec for the westward flow in the South Equatorial Current. Although the total mass transports are derived from 5° square averages of the wind stress, it seems unlikely that a more detailed knowledge of the average wind field would show some of these currents separately in maps of total mass transports.

In the subtropical zone there is a total mass transport to the west. At 120°W the northern boundary of this flow fluctuates only between 3°S and 7°S, while the southern boundary fluctuates considerably between 23°S in winter and 42°S in summer. Only the northern parts of this flow can be identified with the southern parts of the South Equatorial Current, while the larger part of this flow occurs in latitudes where only a weak drift to the west is observed.

The only properly represented flow seems to be the flow to the east occuring south of 40°S and the flow to the north along the coast of Chile although no actual determinations of the mass transports from hydrographic data are available.

The largest discrepancies seem, however, to occur in the area off Peru. The Peru Current flowing north and northwest is not shown at all, but there is a weak total mass transport in the opposite direction. Recent investigations (Wooster and Gilmartin, 1961 and Wyrtki, 1963) have shown that the transport of approximately 10–15 million tons/sec in the Peru Current is offset by powerful subsurface countercurrents.

3. The vertical structure of the circulation off Peru.

Applying Sverdrup's theory, but restricting the Ekman flow to the upper 100 m, using the observed density distribution, and the boundary condition $v_N=0$ along the coast for each individual layer, Wyrtki (1963) has determined the horizontal and vertical field of motion in the area of the Peru Current. The analysis shows among other results that the circulation is essentially different above and below 700 m depth. The layer near 700 m exhibits the smallest horizontal divergence but is not essentially motionless. To demonstrate this difference, the flow pattern in the upper layer (0–700 m) and that in the lower layer (700–3000 m) are shown in Fig. 5. In contrast to the total mass transports, the transports in these two layers are not free of divergence. Therefore some transport lines end or start within the area. A vertical transport of about 2 million tons/sec occurs from the upper layer to the lower layer across the 700 m level. The upwelling off Peru is restricted to much shallower depths, usually to 100 m and less.

The flow pattern in the upper 700 m (Fig. 5a) is composed of the wind drift near the surface and the geostrophic flow in this layer. About 9 million tons/sec enter the area from the south and an equal amount from the north off Punta Aguja. Most of this water leaves the area to the west and northwest, 2 million tons/sec sink into the lower layer because the flow to the south in these low latitudes is highly convergent. This flow pattern is in general agreement with the observed surface circulation. The flow to the south off Punta Aguja continues as a countercurrent to the south separating the Peru Coastal Current from the Peru Oceanic Current. In this map of the integrated transport between the surface and 700 m depth this current is slightly concealed by the wind drift to the west.

Below 700 m depth the flow is almost exactly in the opposite direction (Fig. 5b). Water enters the region from the west and northwest and leaves to the north and south. Because of the much greater thickness of the layer, the horizontal velocities are considerably smaller than those in the upper layer. Superimposition of the two transport maps results in the total mass transport function shown in Fig. 5c. This pattern is essentially the same as that shown for

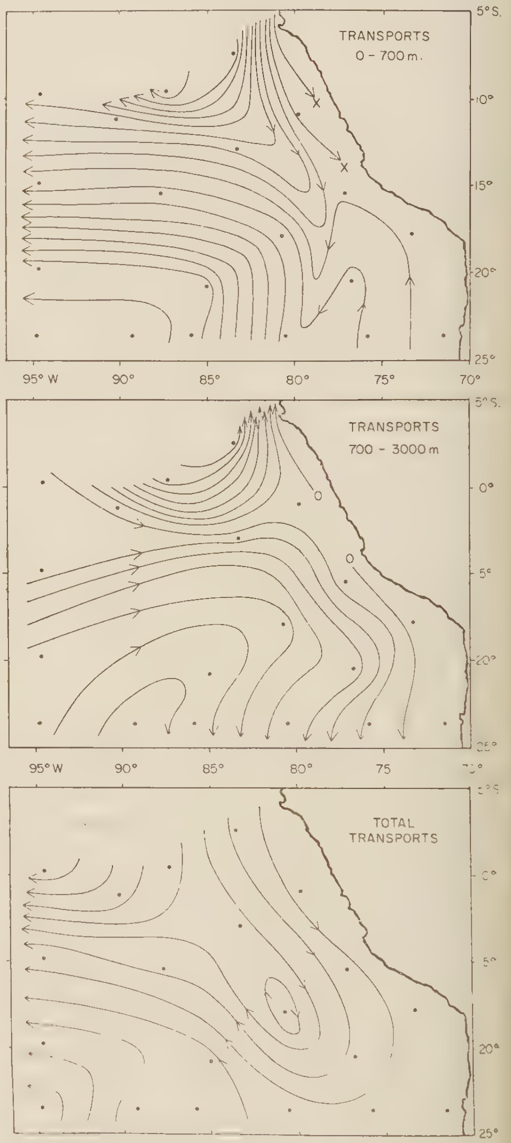

Fig. 5. a. Transports in the upper layer, 0–700 m depth.

b. Transports in the lower layer, 700–3000 m depth.

c. Total mass transports.

The lines equal 1 million tons/sec; X, sink in the upper layer; ∘, source in the lower layer; •, oceanographic stations to 3000 m depth during Step-I Expedition.

the season September through November in Fig. 4 for this part of the region.

There are no direct measurements that could confirm the pattern of the circulation in the lower layer, which is completely based on geostrophic calculations. However, the distribution of properties at surfaces of constant potential specific volume in these depths indicates the presence of a cyclonic flow in the southern parts of this region with water entering from the west and urning south, as shown by TAFT (1963).

4. Discussion and conclusions

The inclusion of the observed distribution of density into Sverdrup's equation, as done for the Peru Current by WYRTKI (1963) has resulted in a much more detailed presentation of the circulation than total mass transports could ever give. The circulation derived shows a surprisingly good agreement with the observed surface circulation and the distribution of water masses. Therefore it can be concluded that Sverdrup's equation to calculate total integrated mass transports is a valuable tool to study ocean circulation, if additional information on the vertical structure of the circulation is added.

The seasonal maps of the total integrated mass transport show a shift of the major circulation features as well as changes in their intensity during the year. These changes must at least be partly attributed to changes in the circulation in the deep layer, which poses the question whether or not ocean circulation can be considered as quasi-stationary with regard to seasonal changes, when applying Sverdrup's equation. WELANDER (1959) has discussed a time-dependent Sverdrup equation and found that the response time is of the order of a few days. In the following discussion, however, he argues against such a short response time. Fluctuations in major ocean currents by as much as a factor of wo have been observed, and the observations of deep currents by Swallow floats show such a high variability that it can be assumed that deep circulation has the ability to react to changing forces within a time which is short compared with seasonal fluctuations. At least for the China Sea it is known (WYRTKI, 1961) that the density field as well as the exchange of water in the upper and lower layers responds completely to the monsoons, which reverse their direction twice a year. Therefore, I think that Sverdrup transports are meaningful, when calculated on an average seasonal and, perhaps, even average monthly basis and when they are interpreted in conjunction with information on the vertical structure of the current systems. Calculations for individual months, as carried out by FOFONOFF (1962), give much larger variations than geostrophic transports relative to 1000 decibars, but this comparison does not include the important baroclinic transport and is carried out in an area of small transports and of a very variable atmospheric circulation. A final decision on whether or not deep circulation responds to seasonal changes of the wind field fast enough to apply a quasi-stationary Sverdrup model, will only come from suitable observations.

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The Thermal Structure of the Eastern Pacific Ocean

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By

KLAUS WYRTKI

Ergänzungsheft Reihe A (8°), Nr. 6
zur Deutschen Hydrographischen Zeitschrift

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Introduction. The purpose of this study is to present an analysis of the thermal structure and of its seasonal variation in the eastern Pacific Ocean. Many features of the thermal structure, like the thickness of the mixed layer, the depth and intensity of the main thermocline and their seasonal fluctuations, are of interest in themselves, but the knowledge of the distribution of these features also forms the basis for further research. A comparison of the thermal structure with estimates of the heat exchange with the atmosphere and of the circulation in the surface layer will give further information about the contribution of advection for maintenance of the thermal structure. Because the seasonal variation of temperature considerably exceeds non-seasonal fluctuations in most parts of the oceans, a quantitative analysis of the processes producing the seasonal fluctuations will result in a better understanding of the processes causing anomalies.

This study covers the area between 30°N and 40°S and from the coast of America to 140°W. Since most of these limits are given neither by geographic nor oceanographic boundaries, the area includes several oceanic regions or parts of them. Entirely covered are the regions of the eastern tropical Pacific Ocean and that of the Peru Current. In the north, the southernmost parts of the California Current and of the California Current extension are included; in the south, parts of the South Equatorial Current and of the subtropical South Pacific Ocean.

Because the number of oceanographic stations and their distribution in time and space were not adequate for an analysis of the thermal structure in this area, data from bathythermograph observations were used. These data give information about temperature to a depth of approximately 250 meters, thus limiting the study to the layer of the ocean above this depth. In large parts of the area this depth is, however, sufficient to penetrate the thermocline. Only in the southwest of the area, near the centre of the subtropical anticyclone of the South Pacific Ocean, the thermocline is situated near this depth.

1. Characteristic Features of the Thermal Structure. In most parts of the tropical and subtropical oceans the thermal structure is characterized by a mixed layer where temperature is almost constant, by the thermocline in which it decreases sharply and substantially, and by a subsurface layer in which temperature still decreases, but at a much slower rate than in the thermocline. In his fundamental work "Die Troposphäre des Atlantischen Ozeans" A. Defant [1936] found that five parameters are essential to describe this structure properly. These are:

1. the temperature of the mixed layer, T_0
2. the depth of the mixed layer, D_0
3. the magnitude of the maximal temperature gradient, $\left(\frac{\partial T}{\partial z}\right)_{\max}$
4. the depth of the maximum temperature gradient, $D_{\max}$
5. the depth of the lower limit of the thermocline, D_2.

Defant has used individual hydrographic stations to determine these five parameters and has charted their distribution without regard to the season because the available number of stations did not allow a more detailed analysis.

There are, however, considerable seasonal variations of most of these parameters in subtropical as well as in tropical regions, and it seems to be warranted to investigate these hanges as soon as the amount of data seems adequate for this purpose. In this study the hermal structure is presented in monthly maps, but this was found to be unnecessary for ome of the parameters if other parameters were introduced.

The depth of the mixed layer and the surface temperature, which is virtually identical o the temperature in the mixed layer, are given for each month. The magnitude of the maxiıum temperature gradient at a particular location exhibits random fluctuations that are of he same order of magnitude as the seasonal variations, so a presentation by months is not ıeaningful. Consequently the average temperature gradient over at least $^2/_3$ of the main hermocline has been charted and only one map is given, showing the average annual conitions.

The thermocline is defined by Defant as the layer in which the temperature gradient xceeds a value of 0.2°C/10 meters, thus giving a precise upper and lower boundary. The

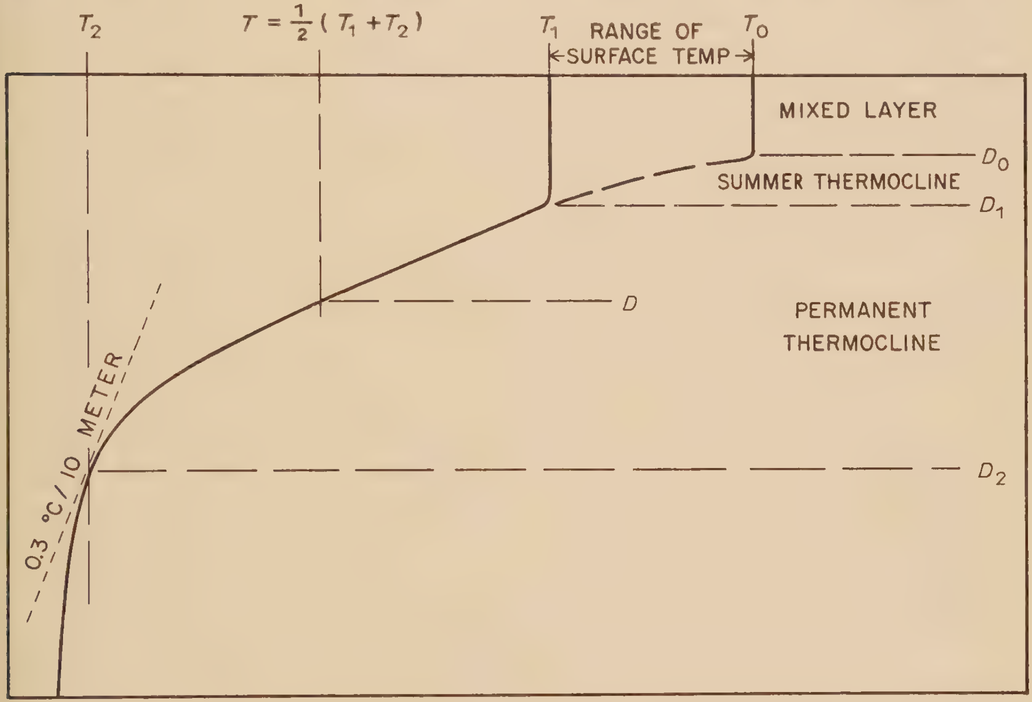

Fig. 1. Notations used for the description of the thermal structure

ıaximum temperature gradient very often occurs close to the upper boundary of the thermoine, especially in tropical regions, while in subtropical regions it is more uniformly distributed ver the entire thermocline. Therefore its depth is probably not the most suitable measure f the depth of the thermocline. The average depth of the upper and lower boundary of the ıermocline, $\frac{1}{2}(D_0 + D_2)$, would also give a misleading presentation because of the strong ıriations of the depth of the mixed layer in subtropical regions and of the formation of rong summer thermoclines above the main thermocline.

A more logical parameter to characterize the depth of the thermocline is the depth of selected isothermal surface. At an isothermal surface the total variation of temperature zero, and thus the fluctuations in its depth represent real fluctuations of the depth of the ıermocline. The selection of a suitable isotherm to represent the depth of the thermocline quires, however, the study of the seasonal variations of the thermal structure at the particar location. To determine the lower boundary of the thermocline, a value of the temperature adient of 0.3°C/10 meters, slightly higher than that used by Defant, was chosen. It was und that in a particular location this occurs at almost the same temperature, irrespective of depth and month. Therefore the lower boundary of the thermocline could be identified by a temperature T_2 (Fig. 1).

In large parts of the oceans, especially in the subtropics, the thermocline consists of a permanent thermocline, which is always present and is sometimes also called the main thermocline, and of a summer thermocline, which is caused by excessive heating during the summer and is often clearly separated from the permanent thermocline situated at greater depths. In this study these two parts of the thermocline will be treated separately.

With this distinction between the permanent thermocline and the summer thermocline in mind it is not difficult to define the range of the permanent thermocline. The upper boundary of the permanent thermocline is given by the depth of the coldest isotherm (T_1) that barely reaches the sea surface during the year. There will be another isotherm with the temperature $T = \frac{1}{2}(T_1 + T_2)$, and its depth is charted for each month to represent the depth D of the centre of the permanent thermocline. An inspection of the diagrams of seasonal variation of the thermal structure (Figs. 63–74, p. 77–82) will show that the choice of a particular isotherm in the centre of the permanent thermocline is a very suitable parameter to characterize its depth.

For this reason no maps of the depth of the maximum temperature gradient are given, but maps showing the difference in temperature between the top and the bottom of the permanent thermocline and the average depth of the lower boundary of the thermocline are added (Figs. 57 and 58, p. 71, 72).

2. The Data and their Processing. A set of data giving the distribution of temperature as a function of location, depth and time lends itself to two basically different ways of analysis. The first possibility is to chart the distribution of temperature for each month at selected depths and to perform the necessary smoothing of the data horizontally within those charts. Since the purpose of this study is to analyse structural features of the temperature distribution, as discussed above, rather than to give absolute temperatures, another way has been preferred. For selected locations, isopleths of the distribution of temperature as a function of depth and time have been constructed and the smoothing of the data is done with respect to depth and time, thus emphasizing the seasonal variation. An analysis using these principles has also been preferred by G. Dietrich [1950] when discussing the thermal structure of the North Sea and the Baltic. As structural features were used, there seems to be no need to discuss the accuracy of the observations.

Approximately 17,000 bathythermograph observations obtained during the years 1941 to 1963 in this area which are on file at the Scripps Institution of Oceanography, are used for this study. This figure is considerably lower than the total number of observations available because only one observation was used if several observations were made on the same day in the same one-degree-square. The data are grouped according to their density into 150 sub-areas. These sub-areas cover from 6 to 10 one-degree-squares along the coast and north of 20°N. Between 20°N and the equator the sub-areas are 2 degrees of latitude and 10 degrees of longitude, thus emphasizing an analysis suitable to detect features of the predominantly zonal circulation in this region. Between the equator and 20°S the sub-areas are 4 degrees in latitude and 10 degrees in longitude, and south of 20°S ten-degree-squares had to be used. The subdivision of the region into sub-areas and the number of observations in each sub-area are shown on Fig. 76 (page 84).

From the bathythermograph traces temperature was read at intervals of 30 meters (100 feet). These temperatures were plotted for each sub-area and each depth as a function of months. Smooth curves were drawn of the average seasonal variation at each depth, and from these curves isopleth diagrams, such as those shown on Figs. 63–74, (p. 77–82), were constructed for each of the 150 sub-areas.

The depth of the mixed layer could usually also be determined from the bathythermograph traces without ambiguity, especially in regions with a strong thermocline below the mixed layer. When evaluating bathythermograph records for this study, a temperature difference up to 0.5°C between the top and the bottom of the mixed layer was allowed if th emperature gradient was uniform. Temperature deviations from homogeneity in the upper meters were also disregarded because it is believed that they are transient local effects. n some instances, especially in upwelling regions, the thermocline occasionally reaches right o the sea surface. No place has been found in the area under consideration where more than 0% of the observations exhibit this behavior in a particular month.

The depths of the mixed layer were plotted for each of the 150 sub-areas and used in onstructing the isopleth diagrams (Figs. 63–74, p. 77–82). From these diagrams, the depth of he mixed layer and the temperatures of the upper and lower boundary of the permanent hermocline, as specified in section 2, were read, as well as the depth of the centre of the ermanent thermocline and other parameters charted in Figs. 29–62 (p. 44–76).

In order to complement the bathythermograph data, sea surface temperature obser-ations are used to determine the seasonal variation of surface temperature for each of the 50 sub-areas, more precisely than it is possible from bathythermograph data. The United tates National Oceanographic Data Center provided listings of average sea surface temperature y one-degree-squares and months from observations made chiefly by merchant ships of many ations during the last 40 years. These data are used to draw maps of sea surface temperature or each month (Figs. 2–13, p. 17–28) and to determine for each of the 150 sub-areas the hanges of sea surface temperature from month to month, charted in Figs. 14–25 (p. 29–40).

The accuracy of the temperatures shown in the monthly charts of sea surface temperature approximately ± 0.4°C if one excludes the possibility of a systematic error that would ffect all temperature observations in the same way. This accuracy varies slightly according the density of observations. Comparing differences in temperature between adjoining ne-degree-squares in regions with weak temperature gradients, it was found that 50% f the differences were smaller than 0.4° C and 95% smaller than 1.2°C. It is well known hat sea surface temperatures over large parts of the oceans can deviate as much as ± 2°C om the long-term average (J. H. Johnson [1961]; J. F. T. Saur and L. E. Eber [1962]; . A. Renner [1963]).

3. The Distribution of Temperature at the Sea Surface. The general distribution of sea urface temperature (Figs. 2–13, p. 17–28) is very similar to that shown in the "Monthly eteorological Charts of the Eastern Pacific Ocean" issued by the British Meteorological ffice [1956] or in the "World Atlas of Sea Surface Temperatures" issued by the U. S. Navy ydrographic Office [1944], but certain features of smaller scale appear more clearly due the fact that one-degree-squares and, probably, more observations have been used. This specially apparent within the tongue of warm water situated from October to May to the est of the cold upwelling water off Peru. This tongue is not shown at all by G. Schott [1935], nd the World Atlas of Sea Surface Temperatures gives much lower temperatures in this ongue. How much of the warming in this tongue is an effect of local heating or of advection ue to the Peru Countercurrent (K. Wyrtki [1963]) still remains to be decided; this has also een pointed out by J. Bjerknes [1961]. The isolated patches of higher temperature occur-ng near 20°S from November to February and between 5°S and 10°S from January to arch cannot be caused by advection and indicate that local heating is important. The maps the change of sea surface temperature from month to month (Figs. 14–25, p. 29–40) show hat an increase of temperature occurs first along the coast of Peru in October and November efore it spreads equatorwards in December and January.

Along the equator temperatures are lower than shown in the World Atlas of Sea Surface emperatures, and the belt of low temperatures is narrower, but temperatures are not as w as given by Schott [1935]. At the equator, lowest sea surface temperatures of less than °C occur southwest of the Galapagos Islands in September. It seems likely that advection cool water from the Peru Current contributes considerably to the lowering of sea surface mperature in this area, while farther west the low temperatures are due to equatorial owelling. Bjerknes [1961] obtained the same results, when comparing contemporary tem-erature maps with older atlasses, but it seems that these differences reflect more comprehen-ve observations contained in the new maps, rather than climatic changes.

From May to November a strong front is developed starting from Ecuador, stretching towards the Galapagos Islands and extending parallel and slightly north of the equator to about 110° W. This front separates the warm waters of the eastern tropical Pacific Ocean from the cooler waters of the Peru Current. The front is probably more sharply developed than shown by the average temperature distribution and will be subject to north-south fluctuations. An example of the thermal structure in the vicinity of such a front is given by T. Cromwell and J. L. Reid, Jr. [1956].

The warm water between the equator and the California Current is characteristic of the eastern tropical Pacific Ocean, but it is by far not as homogeneous as it may seem from the inspection of older sea surface temperature charts. The effects of upwelling are clearly seen in the Gulf of Tehuantepec from November through March (M. Blackburn [1962]) and in the Gulf of Panama from February through April (M. B. Schaefer, Y. M. M. Bishop, and G. V. Howard [1958]). Also the upwelling in the Costa Rica Dome (Wyrtki [1964]) is indicated by lower sea surface temperatures from December through May. Farther to the west, between 110° W and 140° W, the axis of the warmest water is situated between 5° N and 10° N. This axis, shifting slightly with the season, is near 5° N from February to May and near 10° N from July to October, and coincides with the Equatorial Countercurrent, as shown in charts of surface currents by K. Wyrtki [in press].

The Gulf of California has not been included in the investigations because of lack of observations. A study by G. I. Roden and G. W. Groves [1959] gives temperature distributions during five surveys of the Gulf. A more detailed presentation of the sea surface temperature in the Gulf of Panama by Paul N. Sund [1963] is also available. Monthly and half-monthly charts of sea surface temperature for the Pacific Ocean N of 30° S and E of 180° are published by the Bureau of Commercial Fisheries, San Diego.

Charts of sea surface temperature usually do not lend themselves to an evaluation of the local changes of temperature. Therefore charts of the change of sea surface temperature from month to month (Figs. 14–25, p. 29–40) have been prepared from curves of the seasonal variation of temperature determined for the 150 sub-areas. These charts are thought to be suitable for a later comparison with values of the heat balance of the sea surface.

The average annual variation of sea surface temperature (Fig. 26, page 41) shows larger variations than the corresponding map drawn by Schott [1935]. This is especially true in the region of the Peru Current. The largest variations are found in the Peru Current and the California Current as well as in the temperate regions of the South Pacific Ocean and the smallest variations, in the eastern tropical Pacific Ocean.

The two maps showing the occurrence of the temperature maximum and minimum (Figs. 27 and 28, p. 42, 43) exhibit an interesting feature. Although the temperature maximum occurs in late summer and the minimum in late winter in the corresponding hemisphere, the time of occurrence of both, the maximum and the minimum, shows a regular transition from the southern to the northern hemisphere across the equator.

4. The Mixed Layer. The topography of the mixed layer (Figs. 29–40, p. 44–54) is characterized by a sequence of zonal ridges and troughs in the equatorial region. Along the equator the mixed layer is very shallow during the whole year due to equatorial upwelling, and west of the Galapagos Islands the top of the thermocline often reaches the sea surface. A trough near 4° N and a ridge near 10° N indicate the southern and northern boundaries of the Equatorial Countercurrent. The thickness of the mixed layer above this trough and this ridge varies considerably during the year, indicating the varying strength of the Countercurrent. This current is strongest from August to January and weakest from March to June. Farther north and from January to June another trough is situated near 13° N. It indicates the position, where the water flowing southeast off the coast of Mexico turns west into the North Equatorial Current (K. Wyrtki [in press]).

Outside the tropics extremely thick mixed layers are found during the winter. In the central South Pacific Ocean, south of 20° S, the thickness of the mixed layer reaches almost 200 meters in September and October. In the corresponding area of the central North Pacific ean the depth of the mixed layer reaches 120 m in April and May, but greater depths may cur farther to the W and NW, outside of the area covered. In late spring a new summer ermocline and a shallow mixed layer are formed near the surface due to intense heating.

A comparison of these maps with those drawn by T. Cromwell [1958], which were sed on much fewer observations, shows general agreement except in the areas where his ta were scanty. Because of this fact the ridge and trough accompanying the Countercurrent not shown in his maps for January—March and April—June.

In the tropical region the variations of the depth of the mixed layer during the year relatively small (Fig. 41, page 55) while in the subtropical regions much larger variations found. These variations exceed 150 m in the central South Pacific Ocean. Along the coast South America, where upwelling occurs, the variations of the depth of the mixed layer also small.

The map of the depth of the mixed layer drawn by Defant [1936] for the Atlantic ean shows a very similar general pattern, although with much less detail. The mixed layer the South Atlantic Ocean does not seem, however, to reach as deep as in the central South cific Ocean.

5. The Permanent Thermocline. The permanent thermocline, as defined in section 2, is layer between the lower boundary of the thermocline, given by a temperature gradient 0.3°C/10 meters, and the uppermost isotherm that barely reaches the sea surface. Above s permanent thermocline a seasonal or summer thermocline is found in large parts of the eans. The depth of the centre of the permanent thermocline, as defined in section 2, is rted for each month in Figs. 42 — 53 (p. 56–67). The relations of the topography of this er to the circulation of the surface layer are obvious.

There are certain general similarities between the topography of the centre of the rmanent thermocline and that of the mixed layer, but the mixed layer depth fluctuates ch more because of the formation of the summer thermocline. Therefore a direct relation ween the two depths cannot be expected.

Like the depth of the mixed layer, the topography of the permanent thermocline in pical regions is characterized by a sequence of zonal ridges and troughs. Along the equator, depth of the thermocline increases from east to west, but a ridge is developed only from y to December, whereas the mixed layer is very shallow along the equator during the whole r. The southern boundary of the Equatorial Countercurrent near 4°N is marked by a ugh, the northern boundary near 10°N by a ridge. While the position of the trough is y stationary, the position of the ridge exhibits noticeable north-south fluctuations. The rent is strongest from August to January and almost absent from March to June, as also icated in the topography of the mixed layer. From January to June another trough extends r 13°N from 120°W to 95°W.

S of the equator and N of the Equatorial Countercurrent the depth of the tre of the permanent thermocline increases considerably towards the centres of the large tropical anticyclones. The topography of the thermocline indicates clearly the turning of Peru Current into the South Equatorial Current and that of the California Current into North Equatorial Current. The charts of the depth of the permanent thermocline for ober, November and December compare very well with the topography of the surface thermosteric anomaly of 300 cl/ton, which has been drawn by E. B. Bennett [1963] n data of the Eastropic Expedition.

The connection of the topography of the permanent thermocline with the main features he circulation can be seen most clearly from the map of its average depth (Fig. 54, page 68). departures of the depth of the thermocline from its average depth (Fig. 55, page 69) are y small in the regions of the subtropical anticyclones and largest on both sides of the ntercurrent as well as off the coast of Peru. From this map it becomes obvious that the nges in intensity of the Countercurrent are connected with a tilting of the thermocline ınd its central point, and not by either a deeper trough or a shallower ridge. This is demon- ted by a belt of small variation near 8°N and by two belts of strong variations near 5°N and 11°N. The large variations of the permanent thermocline off Peru are probably connected with upwelling to which the very weak permanent thermocline responds easily.

The temperature gradient over at least $^2/_3$ of the permanent thermocline is charted in Fig. 56 (page 70). There are some seasonal variations in the intensity of the temperature gradient, but they do not seem to be documented well enough to be charted. The strongest gradients are found in the tropical region, especially along the northern edge of the Countercurrent where the ridge is developed, in the Costa Rica Dome and off the coast of Ecuador. The gradient is significantly weaker along the equator where the Equatorial Undercurrent is situated. Within the regions influenced by the subtropical anticyclones the temperature gradient is very weak.

The value of the temperature gradient does not however, give a complete impression of the intensity of the thermocline. It is necessary to specify, in addition, the range in temperature over which the thermocline extends or its thickness. Fig. 57 (page 71) shows the difference in temperature between the upper and the lower boundary of the permanent thermocline. This difference characterizes, together with the temperature gradient, the intensity of the thermocline. In the eastern tropical Pacific Ocean a sharp temperature gradient extends over a considerable temperature interval while the upwelling areas off Peru and off California are characterized by a weak temperature gradient extending only over a small temperature interval. In the central South Pacific Ocean a very weak temperature gradient over a large temperature interval characterizes a very thick thermocline layer.

The lower boundary of the thermocline, given by the depth where the temperature gradient drops to less than 0.3°C/10 meters, is shown in Fig. 58 (p. 72). Most of the main features recognizable from the chart of the average depth of the centre of the thermocline (Fig. 54, page 68) are repeated in this map indicating that there is a certain general relationship between the depth of the thermocline and its thickness or intensity.

A comparison of these maps with those drawn by Defant [1936] for the Atlantic Ocean from an analysis of individual hydrographic stations, without consideration of the season, shows remarkable similarities. His map of the depth of the maximum temperature gradient, which is comparable to the map of the average depth of the centre of the permanent thermocline (Fig. 54), shows the same general features. The thermocline is in a shallow depth along the equator and in both upwelling areas along the African coast. It is deepest in the centres of the subtropical anticyclones, and the system of trough and ridge connected with the Countercurrent is also present. Values of the maximum temperature gradient shown by Defant are of the same magnitude as those in Fig. 56 (page 70), and the smaller gradients along the equator are clearly shown.

6. The Summer Thermocline. In areas where the seasonal variation of sea surface temperature is large and the permanent thermocline is relatively deep, a summer thermocline closer to the surface is formed in late spring as an effect of excessive heating. The centre of the summer thermocline is found at shallow depths between about 30 and 70 meters (Fig. 59, p. 73). In some way the summer thermocline can be considered as an extension of the upper parts of the permanent thermocline of the tropical region into the subtropical region of the summer hemisphere. The temperature gradient in the summer thermocline (Fig. 60, page 74) is usually stronger than that in the permanent thermocline (Fig. 56, page 70). The temperature difference between top and bottom of the summer thermocline at the time of its strongest development in late summer of the corresponding hemisphere (Fig. 61, page 75) shows that in some places the summer thermocline can be much more intense than the deeper permanent thermocline (Fig. 57, page 71). This happens along the entire coast of South America. The summer thermocline is developed from late spring to late fall as shown in Fig. 62 (page 76).

7. Types of the Seasonal Variation of the Thermal Structure. The following is an attempt to classify the principal types of seasonal variation of the thermal structure on the basis of the appearance of typical features in the thermal structure that were discussed above. Dietrich [1950] has successfully applied a similar approach to characterize natural regions in the

th Sea and in the Baltic in a study that includes also the haline structure. From the
leth-diagrams constructed for each of the 150 sub-areas twelve have been selected to
esent the characteristic variation of thermal structure in larger parts of the area under
sideration (Figs. 63–74, p. 77–82). The locations represented by the isopleth diagrams are
cated in Fig. 75 (page 83), where the geographical distribution of the types of thermal
icture are also given. The following types of thermal structure are distinguished:

P: Permanent shallow thermocline. Large parts of the tropical ocean are charac-
zed by a permanent thermocline in a relatively shallow position. The temperature gradient
sually strong, considerably exceeding in most places 1°C/10 meters, and the difference of
perature between the top and the bottom of the thermocline is large. The fluctuations
emperature in the mixed layer are small and do not cause the formation of a summer
mocline, but are integrated into the permanent thermocline. Fig. 63 (page 77) is a
cal example for the situation in the eastern tropical Pacific Ocean. The shallow mixed
r is of about 20 m thickness, the strong thermocline has a temperature gradient of about
/10 meters and the temperature fluctuations in the mixed layer are integrated into the
nanent thermocline. A similar situation exists along the northern boundary of the Equa-
l Countercurrent (Fig. 64, page 77), but the depth of the mixed layer and the thermocline
much more during the year. At the equator (Fig. 65, page 78) the permanent thermocline
read over a much larger depth interval, but the temperature gradient is still 1°C/10 meters.
spreading of the isotherms is an effect of the Equatorial Undercurrent.

D: Permanent deep thermocline. This type differs from the previous one only in
ır as the centre of the permanent thermocline is found in more than 150 m depth and the
ed layer is correspondingly deeper. It occurs in those parts of the subtropical anticyclones
face the equator where the variation of surface temperature is still small and no summer
mocline is formed. A typical example is the situation in the South Equatorial Current
.66, page 78). There the mixed layer is deep, the temperature gradient is approximately
10 meters and the temperature difference between the top and the bottom of the thermo-
e is more than 12°C.

PS: Permanent thermocline with additional summer thermocline. In areas
e the seasonal variation of the heat exchange at the sea surface is large, a summer thermo-
is formed above the permanent thermocline. The temperature gradient in the permanent
mocline is usually weaker than that in the summer thermocline, and the mixed layer is
ow in summer and deep in winter. The Peru Current and the southern parts of the Cali-
a Current are the regions where this type is found. Fig. 67 (page 79) shows the situation
e off-shore area of the California Current, and Fig. 68 (page 79) that in the upwelling area
g the coast. The difference between the two areas is not only a higher position of the
erms and a lower surface temperature, but a much weaker permanent thermocline in
upwelling area. It is obvious from the two diagrams that the summer thermocline is
rimposed on the permanent thermocline, which exhibits little variation in depth.

The two corresponding diagrams for the region of the Peru Current and its upwelling
(Figs. 69 and 70, page 80) show a similar situation. The permanent thermocline is even
ker and the summer thermocline stronger than in the California Current. The variation
mperature in the mixed layer is strong and the summer thermocline is very intense. The
h of the centre of the permanent thermocline fluctuates considerably in depth, especially
e upwelling area.

PSW and DSW: Permanent thermocline with a summer thermocline form-
in the upper portions of the deep mixed layer of the preceding winter.
e central parts of the subtropical anticyclones, where the permanent thermocline is at
y deep position and where the seasonal variation of sea surface temperature becomes
, an extensive mixed layer is formed during the winter. The depth of this mixed layer

usually increases during the whole winter until, in late spring, heating becomes strong enough to form a shallow summer thermocline on top of the huge mixed layer. In the early phases of this development the newly formed summer thermocline is clearly separated from the much deeper permanent thermocline by a homogeneous layer having the temperature of the winter water. This situation is shown in Fig. 71 (p. 81) for an area approximately 1000 km off Peru, in Fig. 72 (page 81) for the central South Pacific near the Easter Islands and in Fig. 7 (page 22) for the part of the central North Pacific covered in this study.

S: Summer thermocline only. A permanent thermocline is no longer thought to exist in areas where a temperature gradient of more than 0.3°C/10 meters occurs over a temperature interval of less than 2°C. In this area, however, a summer thermocline may be formed as is the case off Chile to the south of 30°S (Fig. 74, page 82).

The distribution of these types of variation of the thermal structure (Fig. 75, page 83) is closely related to oceanic regions and to current systems. A permanent shallow thermocline (Type P) is characteristic of the region described as the eastern tropical Pacific Ocean, which is bordered in the north by the California Current system and in the south by the Peru Current system, both having a different thermal structure. West of 130°W in the northern hemisphere, and west of 100°W in the southern hemisphere, regions with a permanent deep thermocline (Type D) appear on both sides of the region with a permanent shallow thermocline. These regions with a permanent deep thermocline are typical for northern portions of the North Equatorial Current and the southern portions of the South Equatorial Current. While the permanent shallow thermocline characterizes the inner tropical region, the permanent deep thermocline characterizes the outer tropical region.

The subtropical region is characterized by the appearance of a summer thermocline. The regions with a very deep mixed layer in winter (Type DSW) coincide with the centres of the large subtropical anticyclones. In the regions of the California and of the Peru Current systems, the permanent thermocline is in a shallow position, related to the upwelling along these coasts, and a summer thermocline is formed indicating their subtropical character (Type PS). The regions with this subtropical type of thermal structure extend far towards the equator, thus indicating the effect of these current systems on the distribution of oceanic climate.

Along the coast of Chile, south of 30°S, a subantarctic type of thermal structure is found (Type S), characterized by the development of a thermocline only during the summer and by the absence of a pronounced permanent thermocline.

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Summary. Bathythermograph observations are used to analyze the seasonal variation of the thermal structure of the eastern Pacific Ocean between 30°N and 40°S and between 140°W and the American coast. Monthly charts of the following parameters are given: sea surface temperature, change of sea surface temperature from month to month, depth of the mixed layer, and depth of the centre of the permanent thermocline. They are supplemented by charts of the average annual variation of surface temperature, occurrence of maximum and minimum temperature, temperature gradient in the thermocline, variation of the depth of the thermocline, temperature difference within the thermocline, and characteristic features of the summer thermocline. For twelve selected locations the average annual variation of the thermal structure is shown in isopleth diagrams. An analysis of types of seasonal variation of the thermal structure has been made using features like the depth of the permanent thermocline, the occurrence of a summer

mocline, and the occurrence of a very deep mixed layer in winter. These types of variation
hermal structure are characteristic of certain oceanic regions.

Der thermische Aufbau des östlichen Pazifischen Ozeans (Zusammenfassung). Beobach-
gen von Bathythermographen werden verwendet, um die jahreszeitliche Schwankung des ther-
chen Aufbaues des östlichen Pazifischen Ozeans zwischen 30° N und 40° S und zwischen 140° W
der amerikanischen Küste zu untersuchen. Der thermische Aufbau in diesen tropischen und
ropischen Meeresteilen ist charakterisiert durch eine durchmischte Schicht an der Oberfläche
durch die darunterliegende Sprungschicht. Eine nähere Analyse zeigt, daß diese Sprung-
cht aus einem permanenten, während des ganzen Jahres vorhandenen Teil besteht und aus
r zusätzlichen sommerlichen Sprungschicht, die vorwiegend in den subtropischen Gebieten
vickelt ist. Als untere Grenze der thermischen Sprungschicht wird ein Temperatur-Gradient
0,3° C/10 m angenommen, wobei es bemerkenswert ist, daß dieser Gradient an einem bestimm-
Ort immer bei nahezu der gleichen Temperatur auftritt, unabhängig davon, in welcher Tiefe
ch befindet. Als obere Grenze der permanenten Sprungschicht wird die niedrigste Temperatur
durchmischten Schicht angenommen, die während des Jahres auftritt. Das Zentrum der
nanenten Sprungschicht ist dann durch die Tiefenlage derjenigen Isotherme gegeben, die dem
elwert der Temperatur an der oberen und unteren Grenze entspricht.

Auf Grund dieser Überlegungen werden die folgenden Parameter in Monatskarten dar-
ellt: Oberflächentemperatur, die auch die Temperatur der durchmischten Schicht darstellt,
der durchmischten Schicht und Tiefenlage des Zentrums der permanenten Sprungschicht.
tzlich sind Karten der Änderung der Temperatur an der Oberfläche von Monat zu Monat
ben, die einen einfachen Überblick über die Erwärmung und Abkühlung der Meeresoberfläche
atten. Diese Karten werden vervollständigt durch Karten der mittleren jährlichen Schwan-
der Oberflächentemperatur, der Eintrittszeit ihres Maximum und Minimum, des Temperatur-
lienten in der Sprungschicht, der Variation der Tiefenlage der Sprungschicht und des Tem-
turunterschiedes zwischen der oberen und unteren Grenze der Sprungschicht, sowie durch
en, die charakteristische Eigenschaften der sommerlichen Sprungschicht darstellen. Bei der
beitung stellte es sich heraus, daß nahezu überall die Schwankungen in der Intensität des
peratur-Gradienten in der permanenten Sprungschicht während eines Monats ebenso groß sind
liejenigen während des ganzen Jahres. Deshalb wird nur eine Karte des mittleren Temperatur-
ienten dargestellt, der in mindestens zwei Drittel der permanenten Sprungschicht über-
tten wird.

Diese Karten der Mächtigkeit der durchmischten Schicht und der Tiefenlage des Zentrums
ermanenten Sprungschicht werden mit den wichtigsten Zweigen der Zirkulation verglichen,
i sich deutliche Zusammenhänge erkennen lassen.

Für zwölf ausgewählte Punkte wird die mittlere jährliche Veränderung des thermischen
aues in Isoplethen dargestellt. Eine Analyse von typischen jahreszeitlichen Veränderungen
hermischen Aufbaues wird auf Grund der Tiefenlage der permanenten Sprungschicht, des
etens einer sommerlichen, zusätzlichen Sprungschicht und einer extrem tiefen, winterlichen
mischten Schicht vorgenommen. Diese Typen der jahreszeitlichen Veränderung des ther-
nen Aufbaues sind charakteristisch für gewisse ozeanische Regionen.

Eine permanente Sprungschicht mit einer dünnen durchmischten Schicht ist charakteristisch
ie Region des östlichen tropischen Pazifischen Ozeans. Eine permanente Sprungschicht in
v tiefer Lage charakterisiert die Teile der Nord- und Süd-Äquatorial Strömung, die vom
tor abgewandt sind. Eine permanente Sprungschicht mit einer zusätzlichen sommerlichen
gschicht findet sich in den südlichen Teilen der Kalifornischen Strömung und der Peru-
nung, wo die jahreszeitliche Schwankung der Oberflächentemperatur erheblich wird. Eine
v tiefe permanente Sprungschicht mit einer zusätzlichen sommerlichen Sprungschicht und
sehr tiefen, winterlichen durchmischten Schicht kennzeichnet die subtropischen Regionen
ord- und Süd-Pazifischen Ozeans, soweit sie in dieser Bearbeitung eingeschlossen sind.

La structure thermique de la partie est de l'océan Pacifique (Résumé). On se sert des obser-
ns faites à l'aide de bathythermographes pour étudier les variations saisonnières de la struc-
hermique de la partie est de l'océan Pacifique entre 30° latitude N et 40° latitude S d'une
et 140° longitude W et la côte américaine, d'autre part. Les paramètres suivants se trouvent
sentés sur les cartes mensuelles: température de la surface, variations de la température de
en mois, la profondeur de la couche de mélange, et la profondeur du centre de la couche
ique de discontinuité. On a complété ces cartes par des cartes montrant la variation annuelle
nne de la température superficielle, l'entrée du maximum et du minimum de la température,
ée du gradient de la température dans la couche de discontinuité, la variation de la situation
ofondeur de la couche de discontinuité et celle de la différence de la température entre la
supérieure et inférieure de la couche permanente de discontinuité. En outre, on présente des
montrant des propriétés caractéristiques de la couche estivale de discontinuité. Pour douze
its choisis on a représenté par des isoplèthes la variation annuelle moyenne de la structure
ique. Partant des particularités comme la situation en profondeur de la couche permanente
continuité, la présence d'une couche estivale additionnelle de discontinuité ainsi que la pré-

sence d'une couche hivernale de mélange située en profondeur extrême, on fait l'analyse de divers types des variations annuelles caractéristiques de la structure thermique. Ces types de la variation saisonnière de la structure thermique sont caractéristiques de certaines régions océaniques.

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Eingegangen im Februar 1964

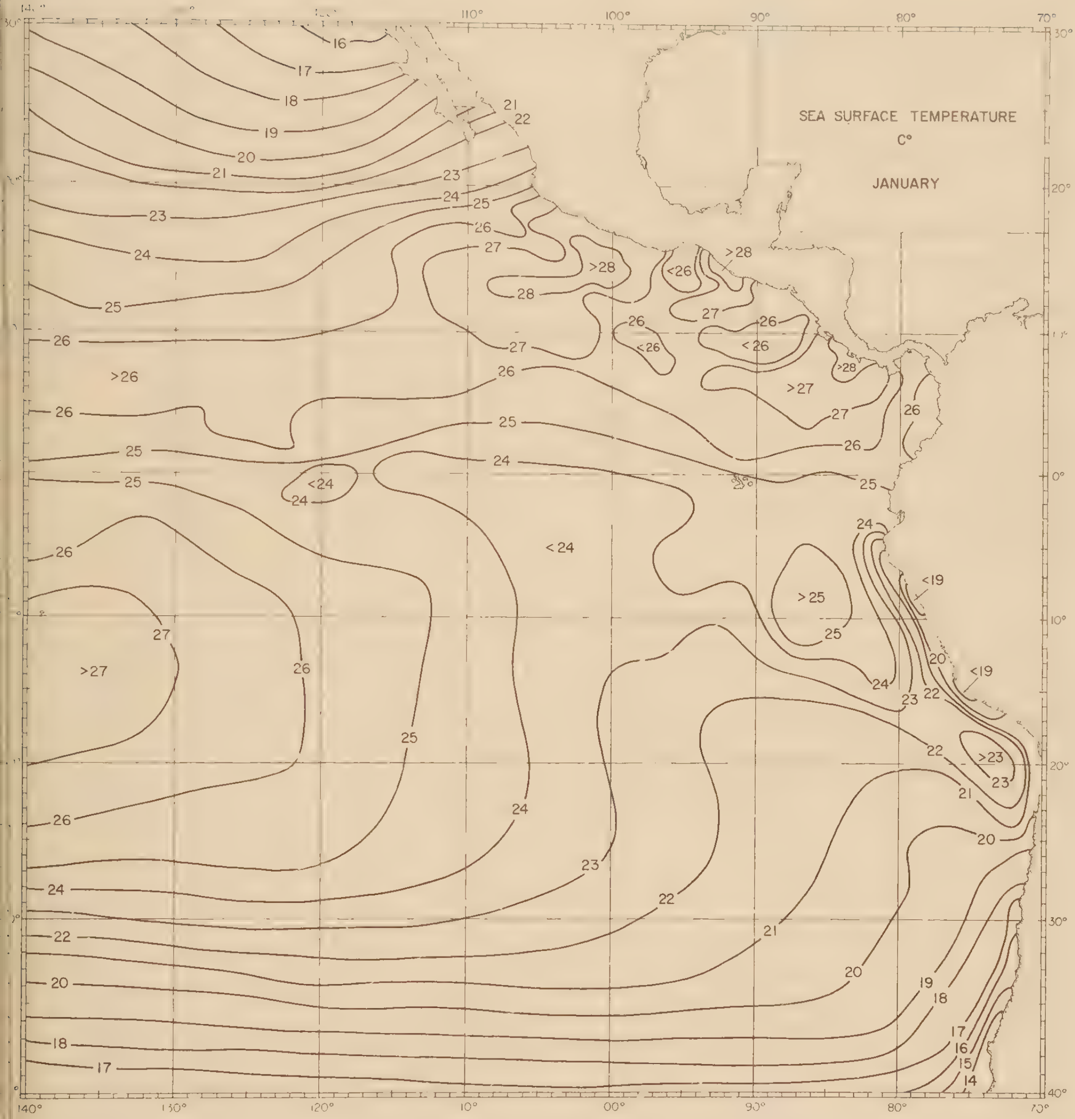

Fig. 2. Distribution of sea surface temperature in °C for January

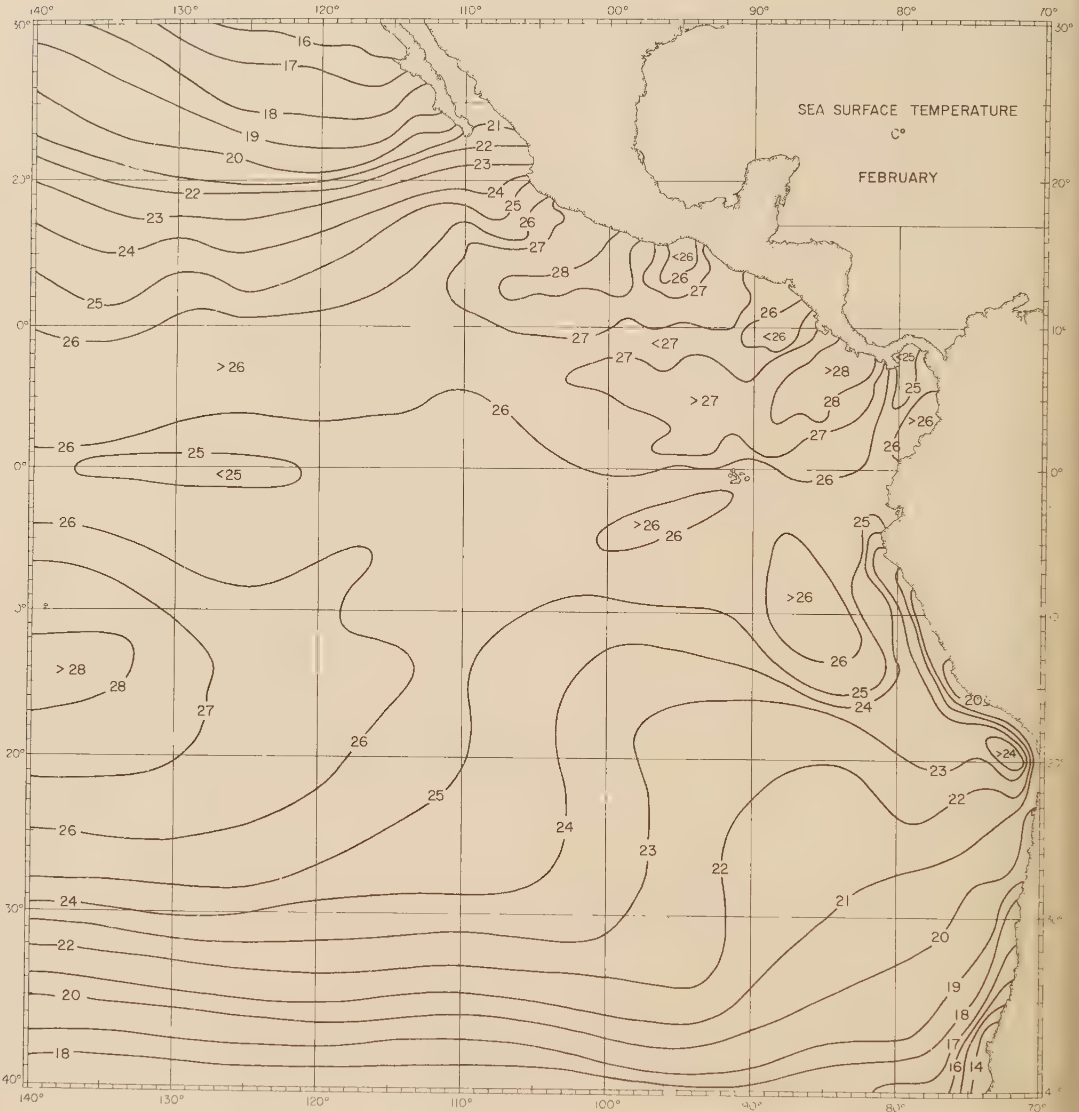

Fig. 3. Distribution of sea surface temperature in °C for February

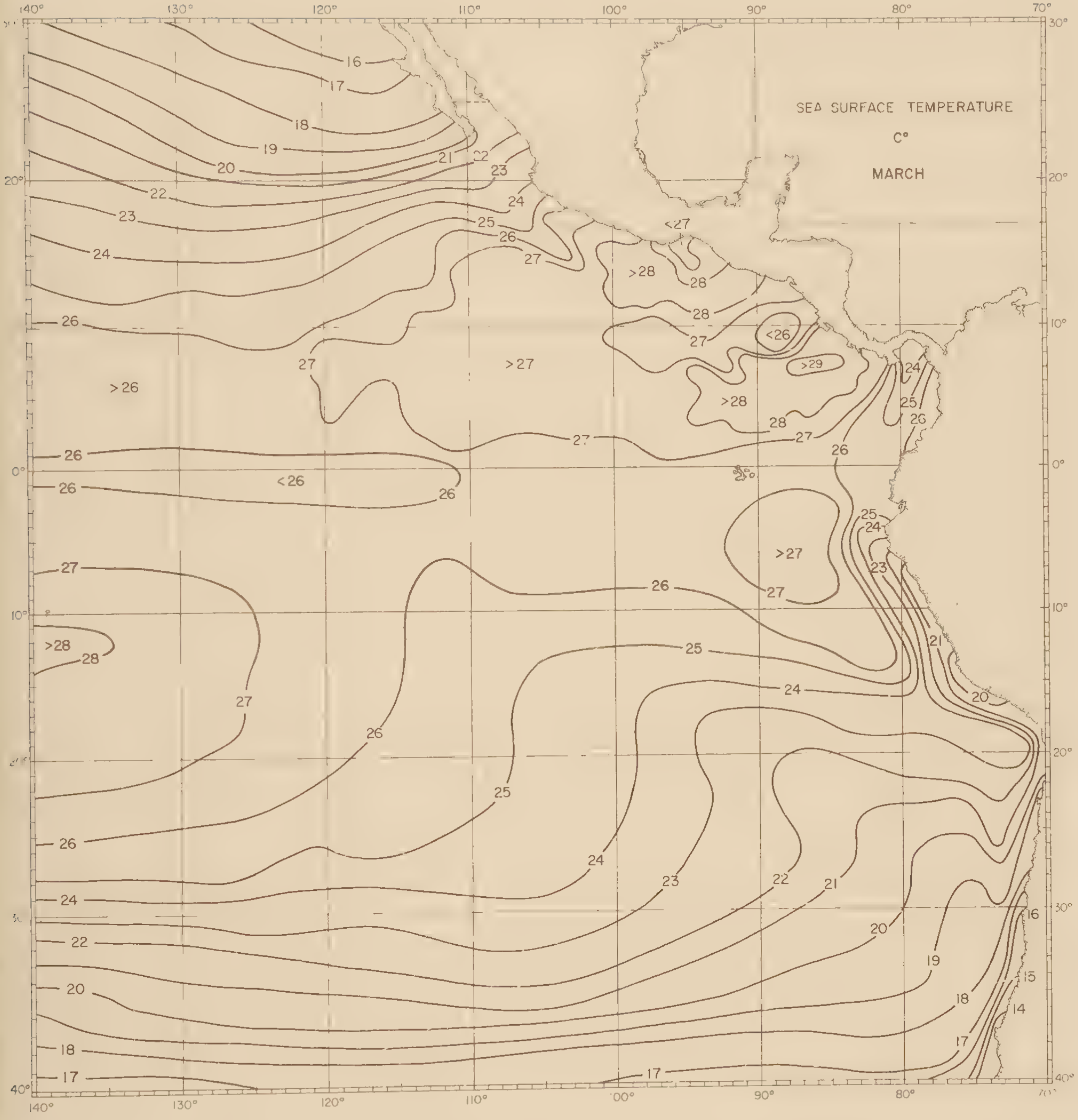

Fig. 4. Distribution of sea surface temperature in °C for March

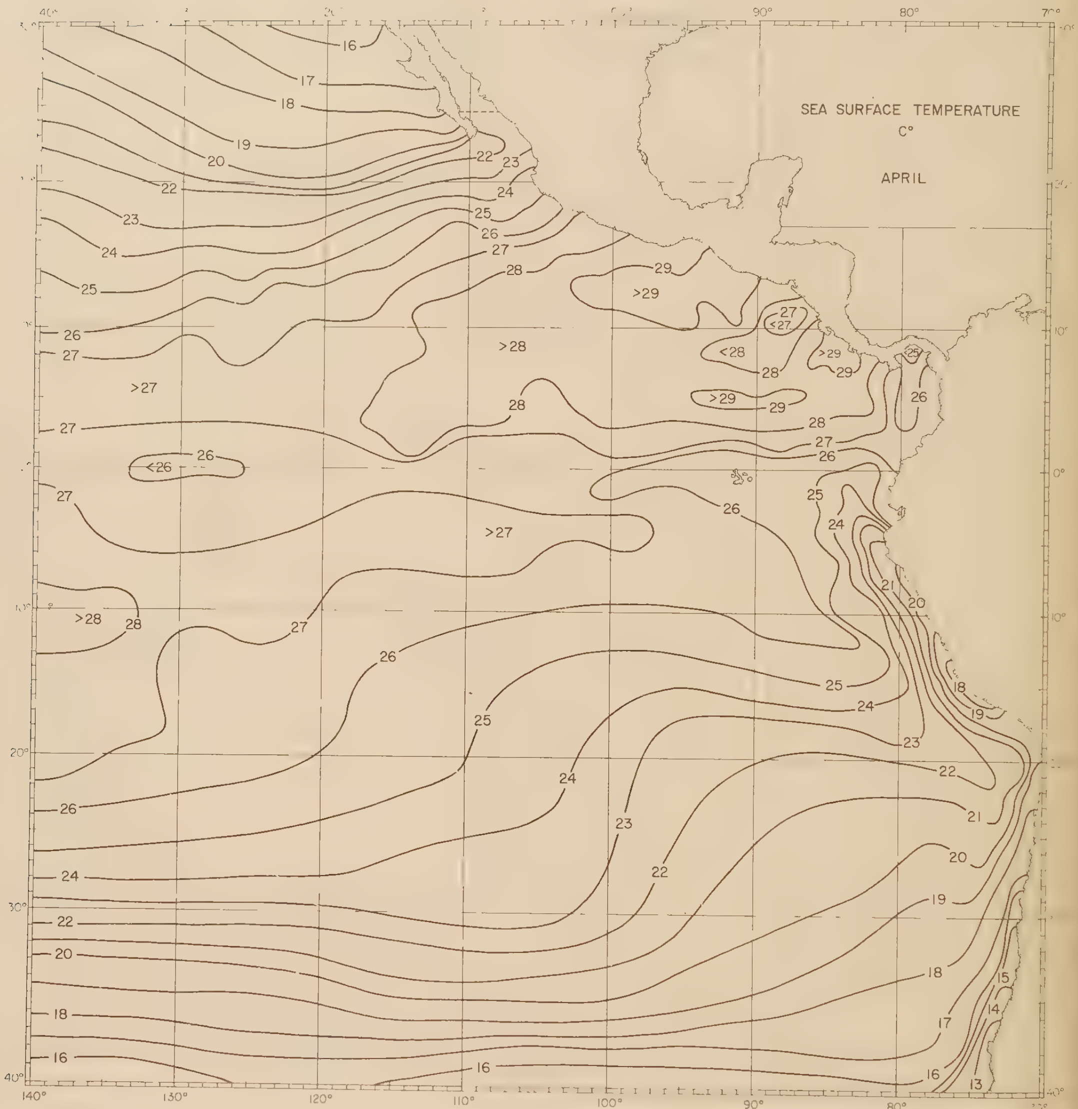

Fig. 5. Distribution of sea surface temperature in °C for April

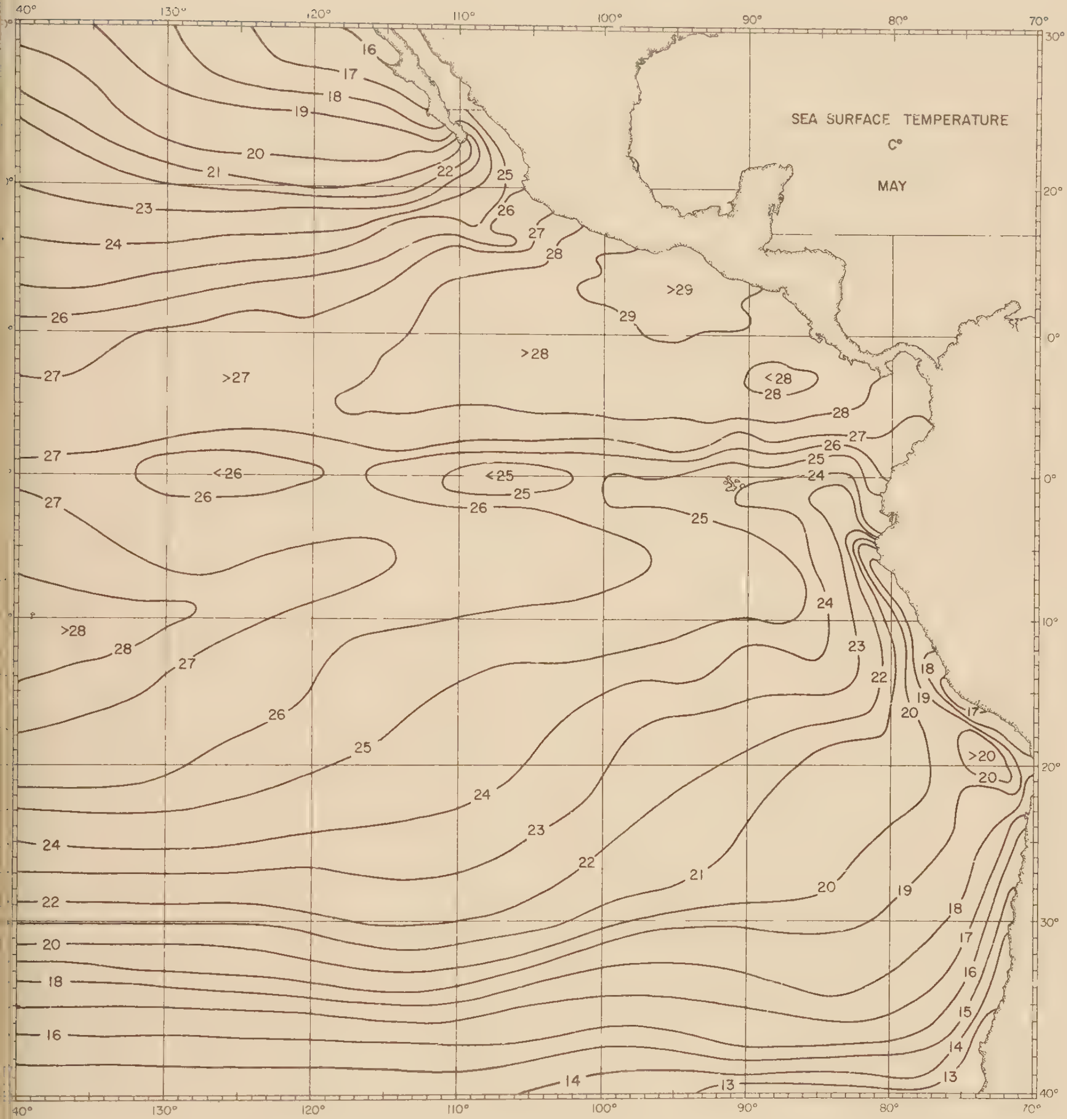

Fig. 6. Distribution of sea surface temperature in °C for May

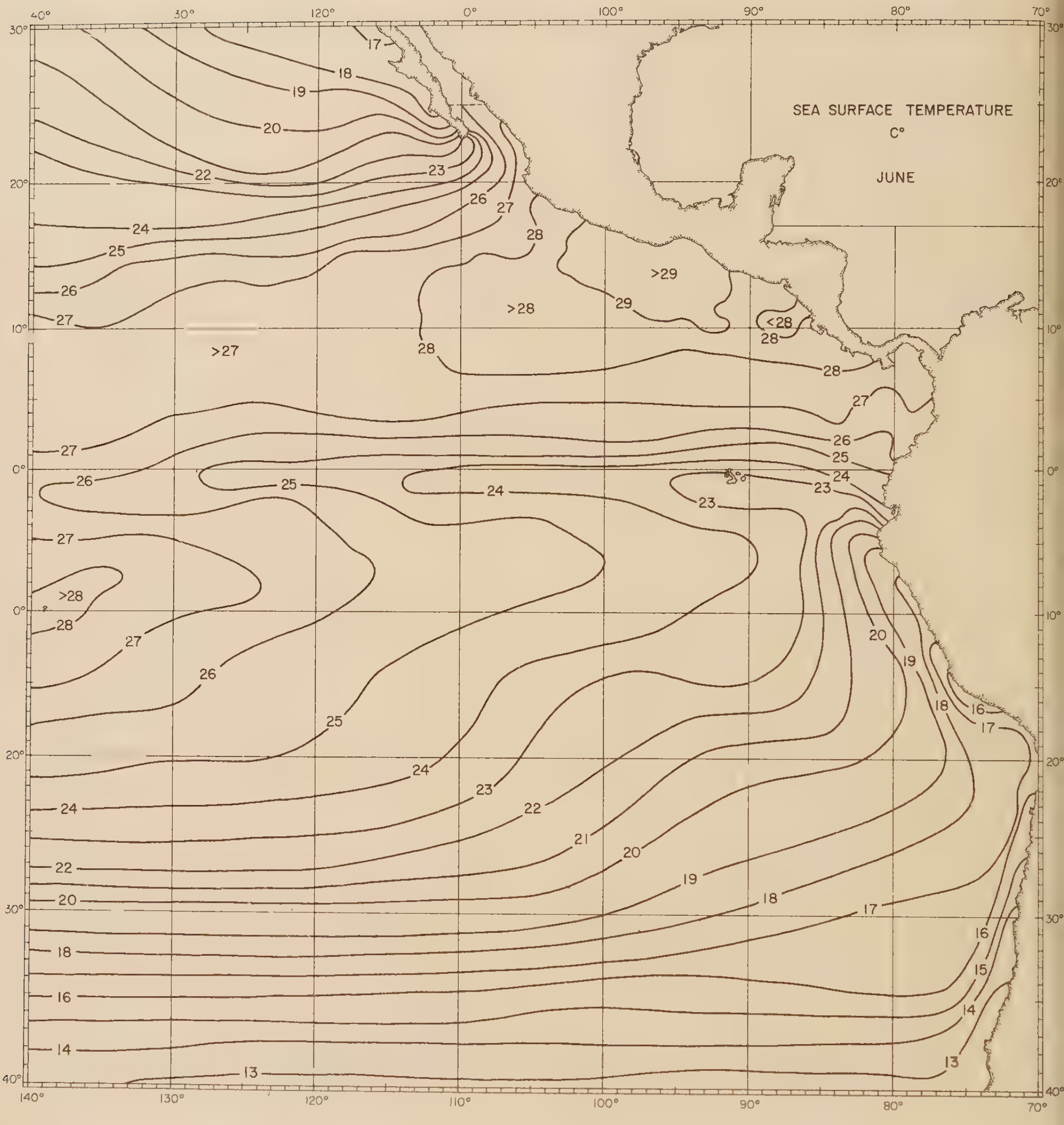

Fig. 7. Distribution of sea surface temperature in °C for June

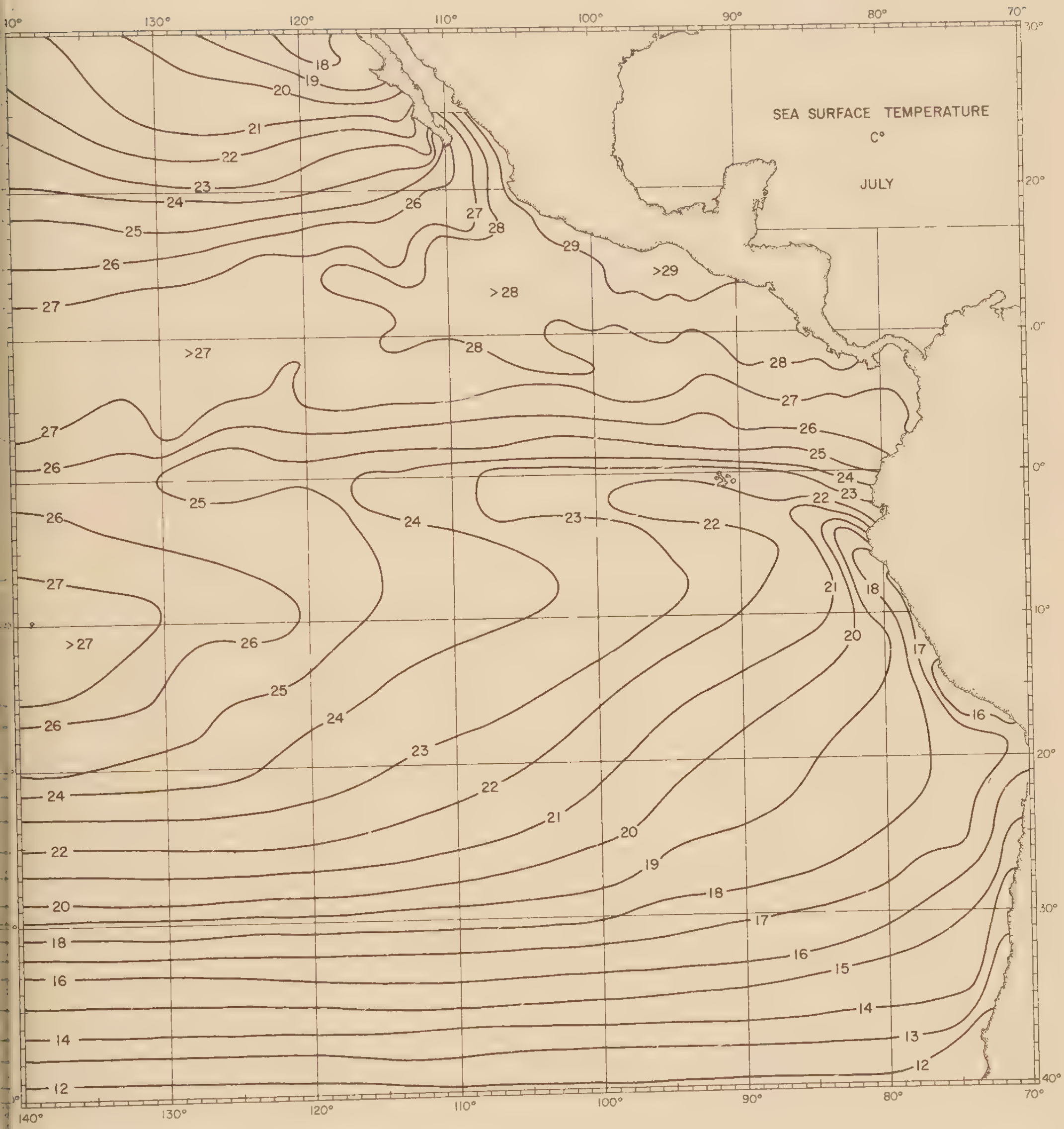

Fig. 8. Distribution of sea surface temperature in °C for July

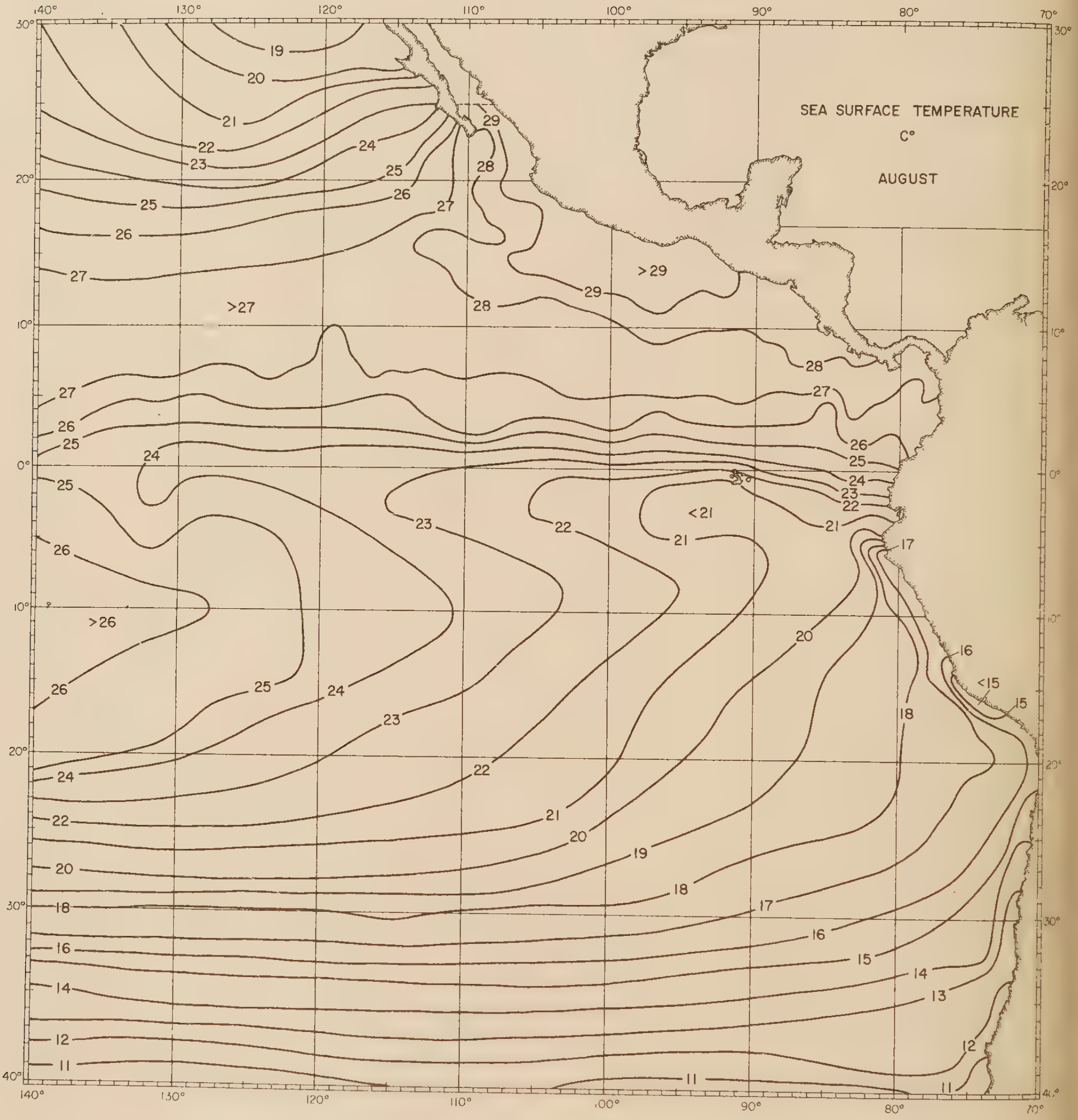

Fig. 9. Distribution of sea surface temperature in °C for August

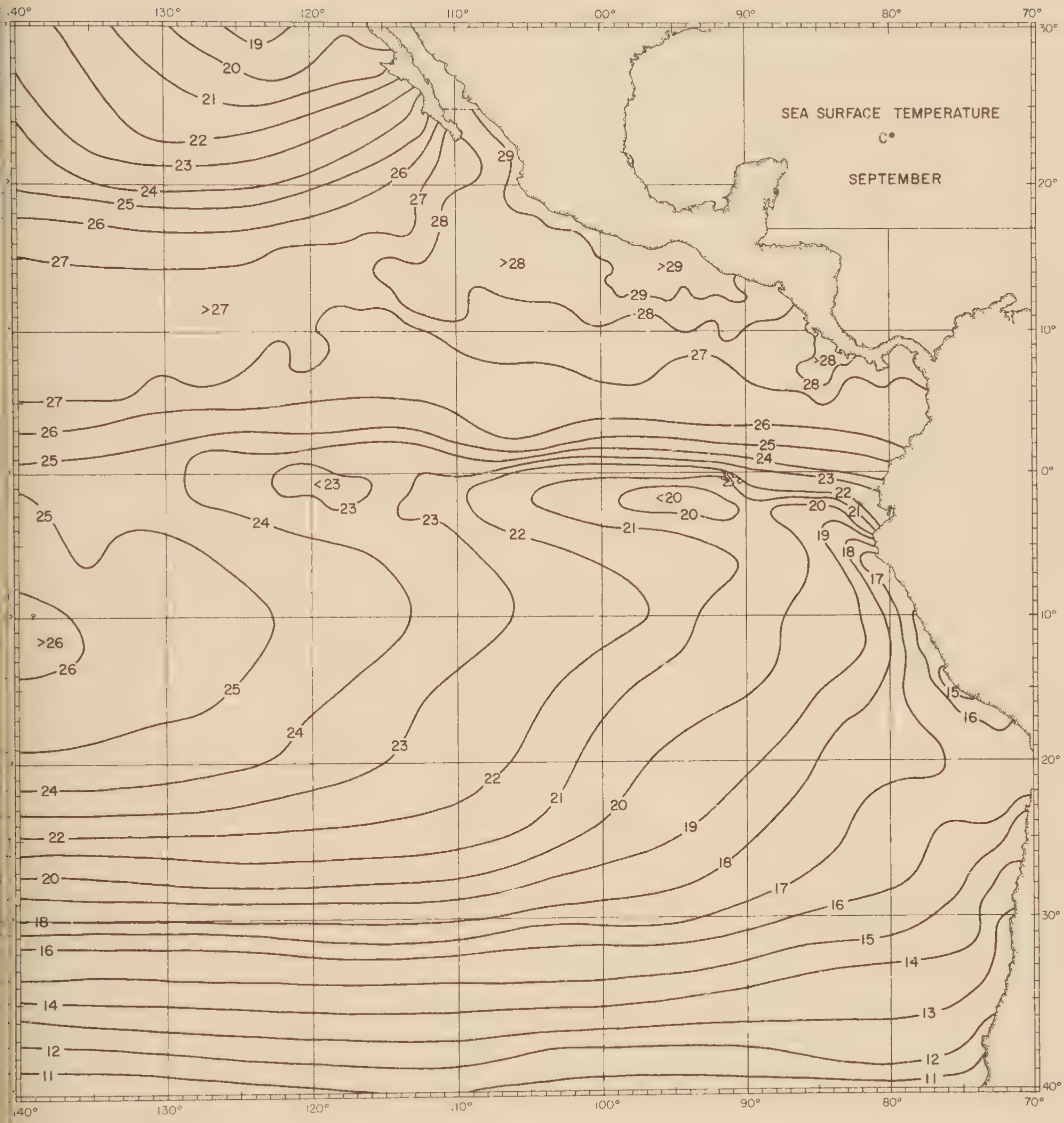

Fig. 10. Distribution of sea surface temperature in °C for September

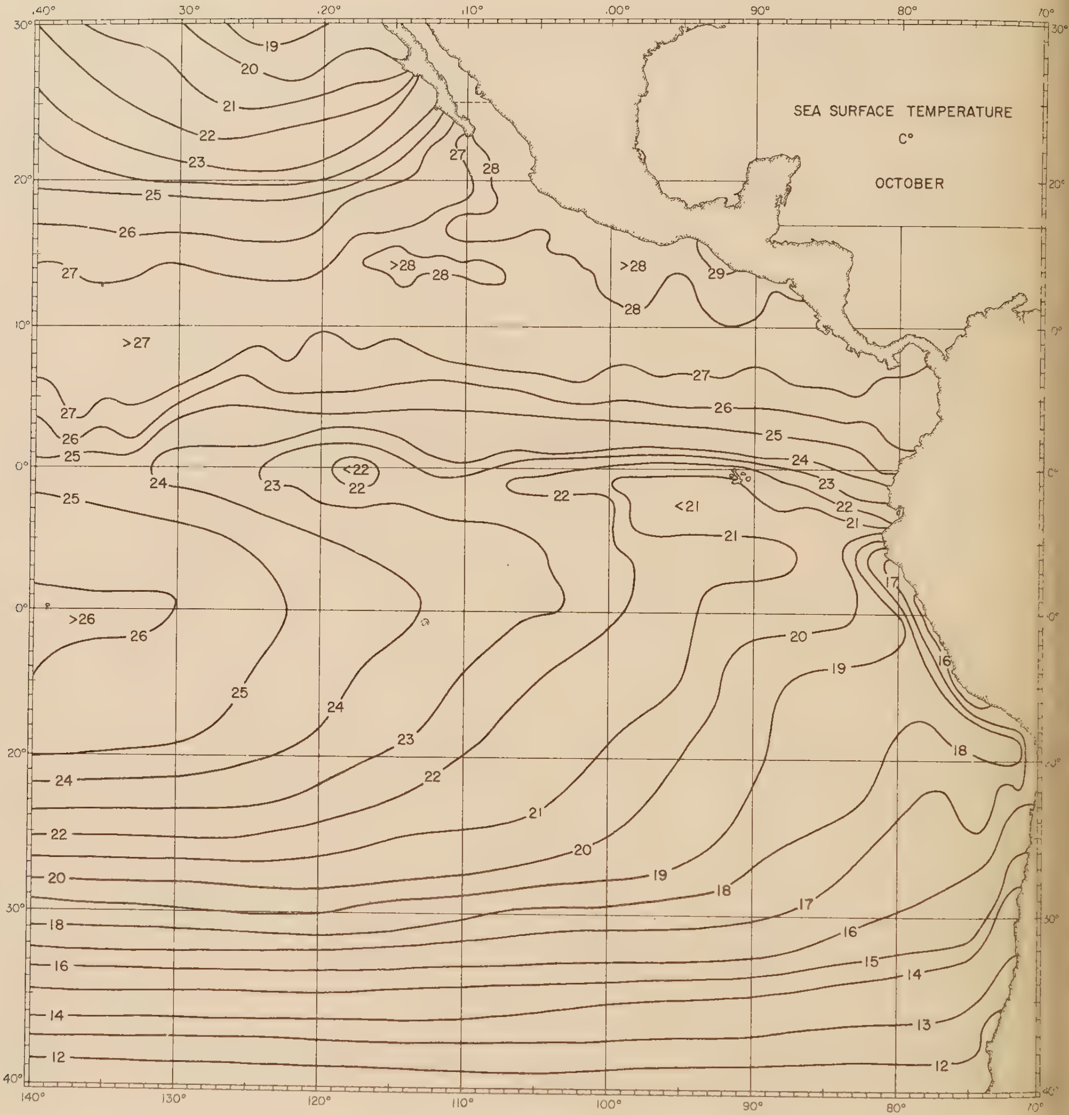

Fig. 11. Distribution of sea surface temperature in °C for October

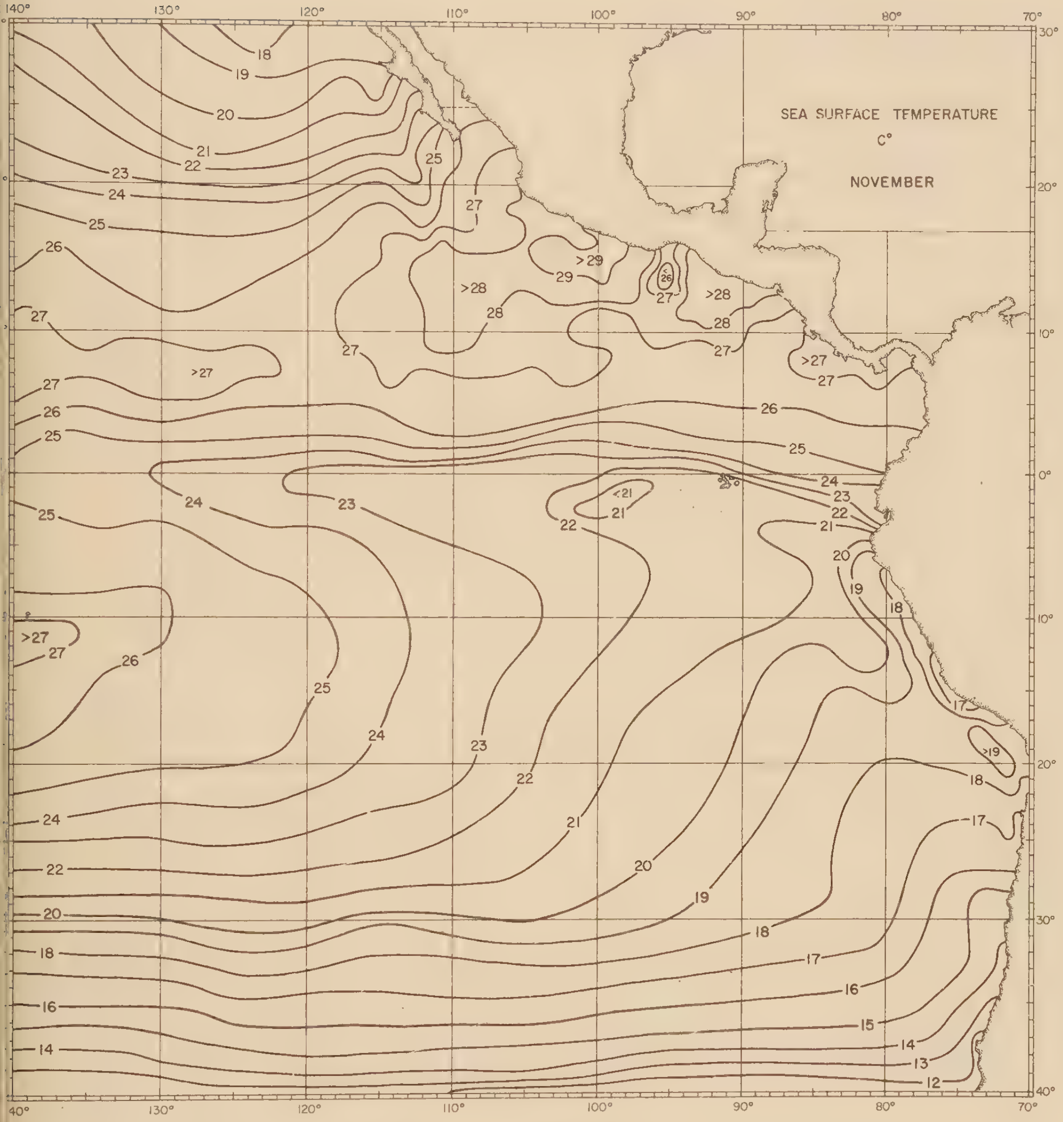

Fig. 12. Distribution of sea surface temperature in °C for November

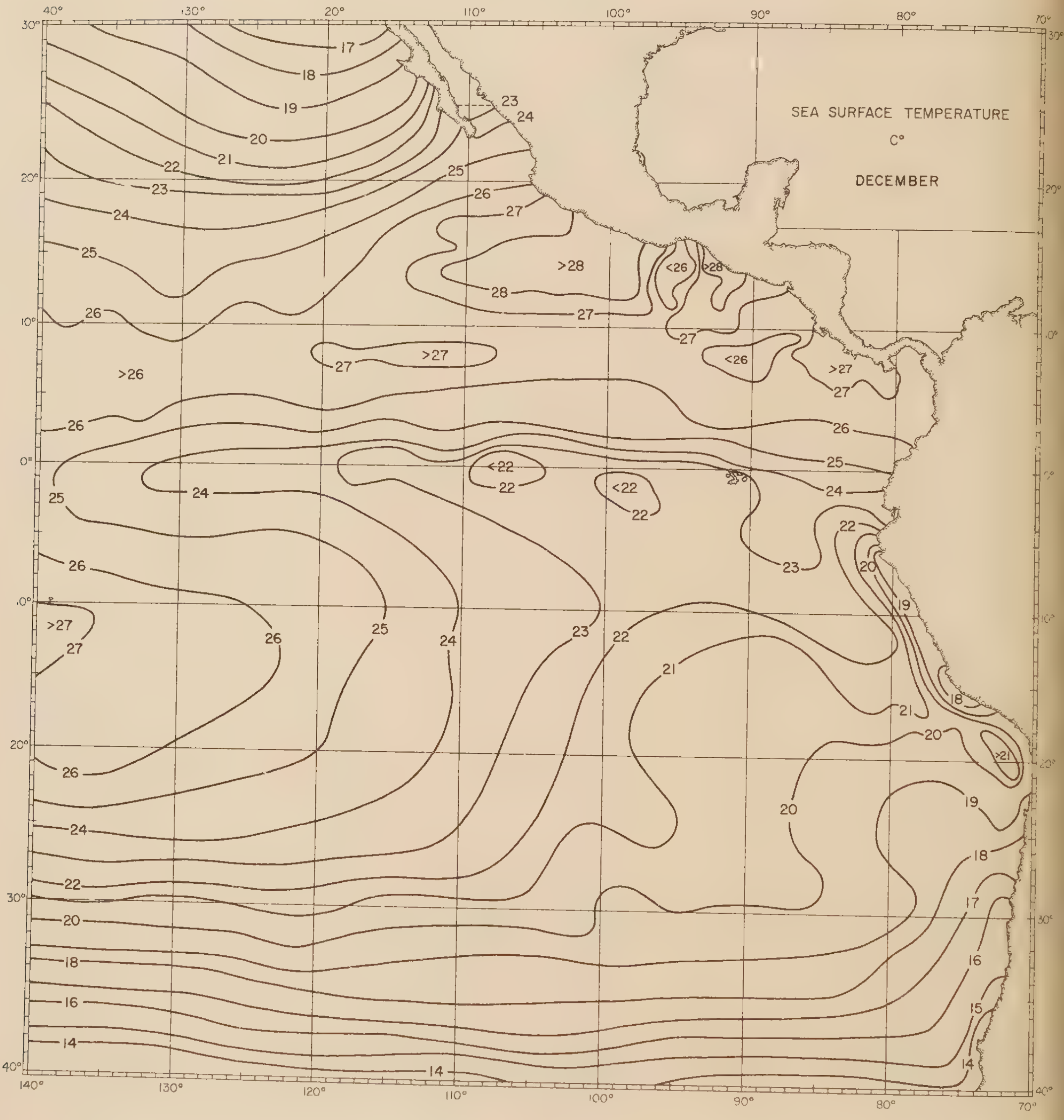

Fig. 13. Distribution of sea surface temperature in °C for December

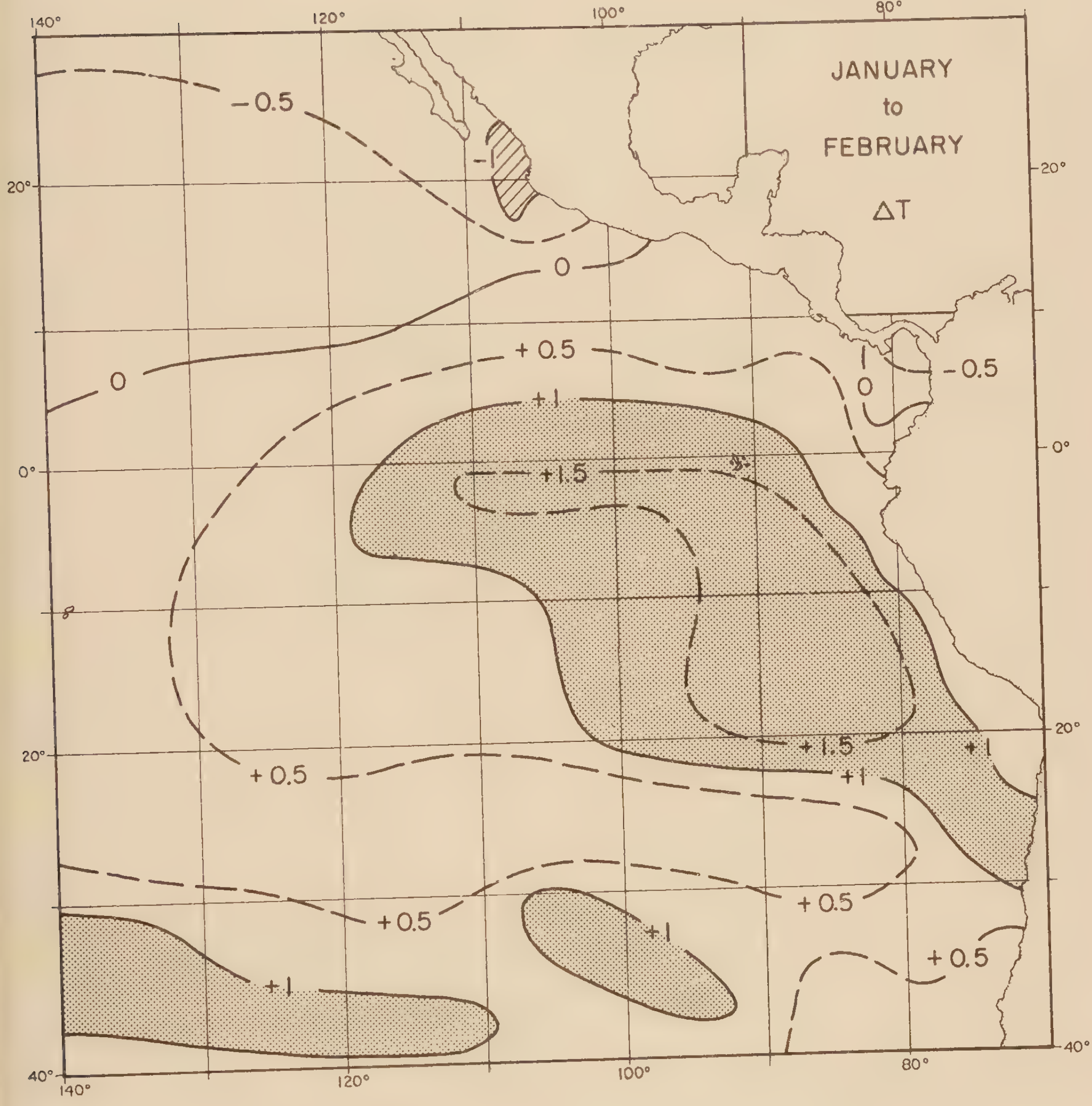

Fig. 14. Change of sea surface temperature from January to February in °C

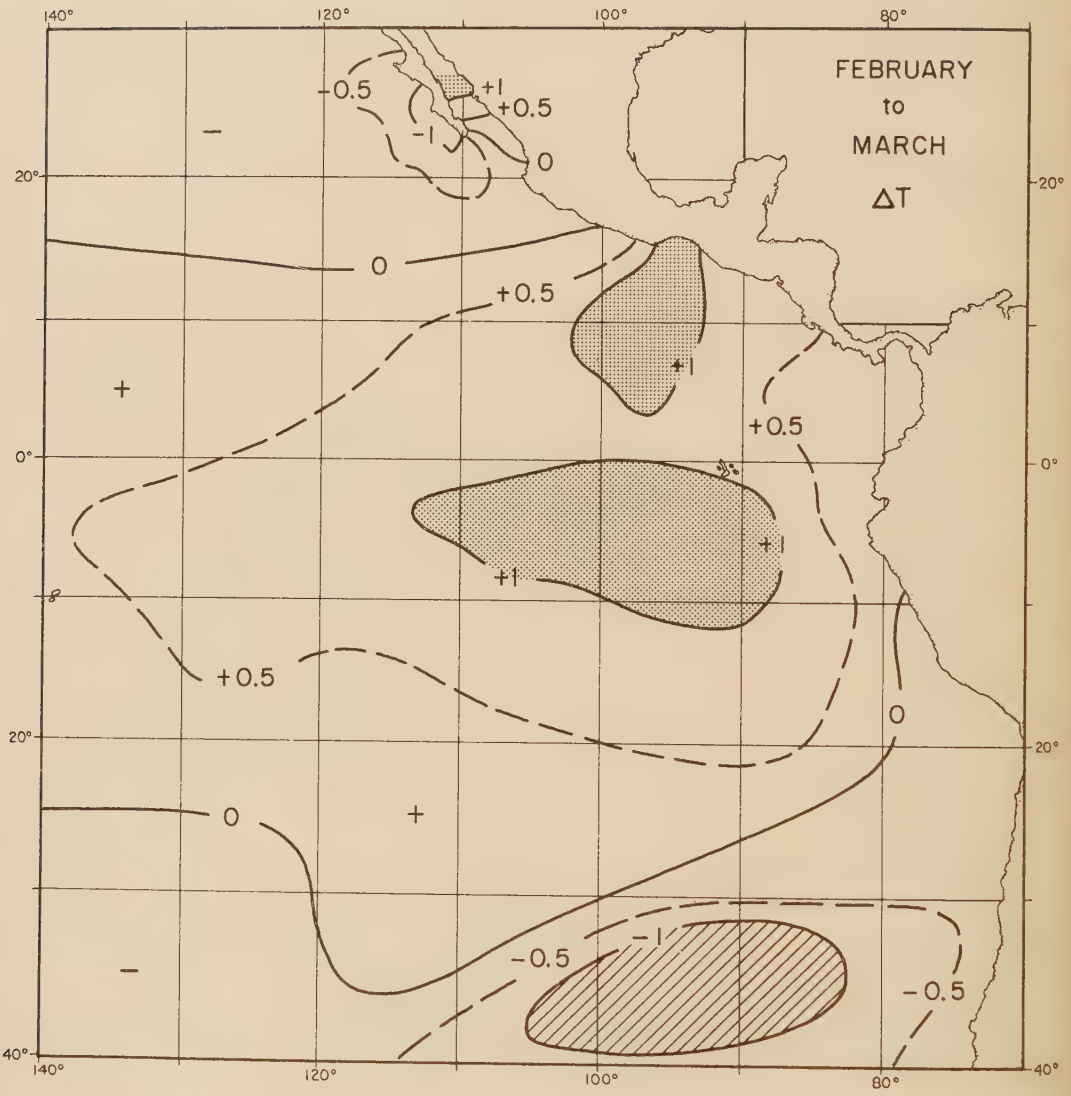

Fig. 15. Change of sea surface temperature from February to March in °C

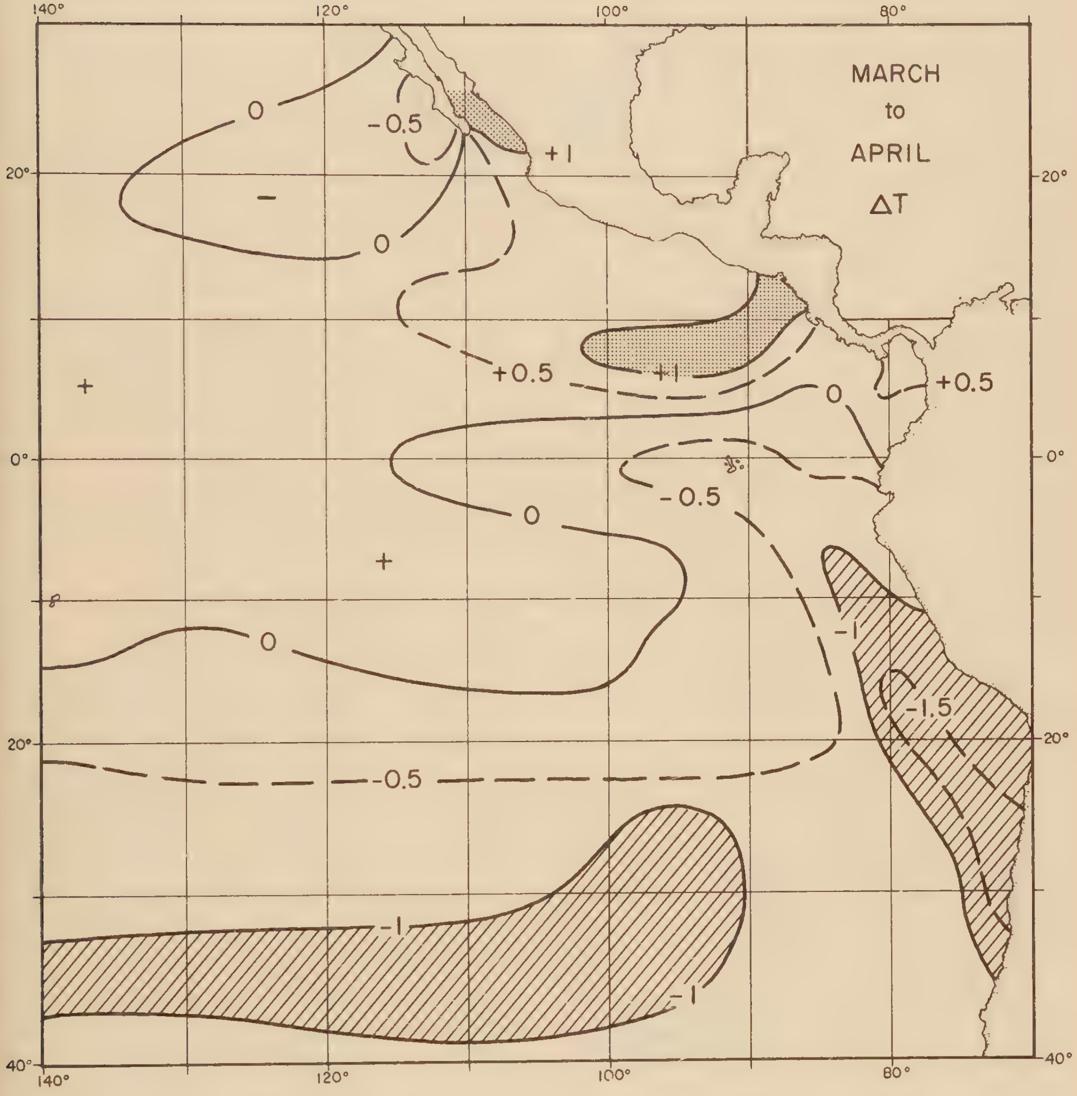

Fig. 16. Change of sea surface temperature from March to April in °C

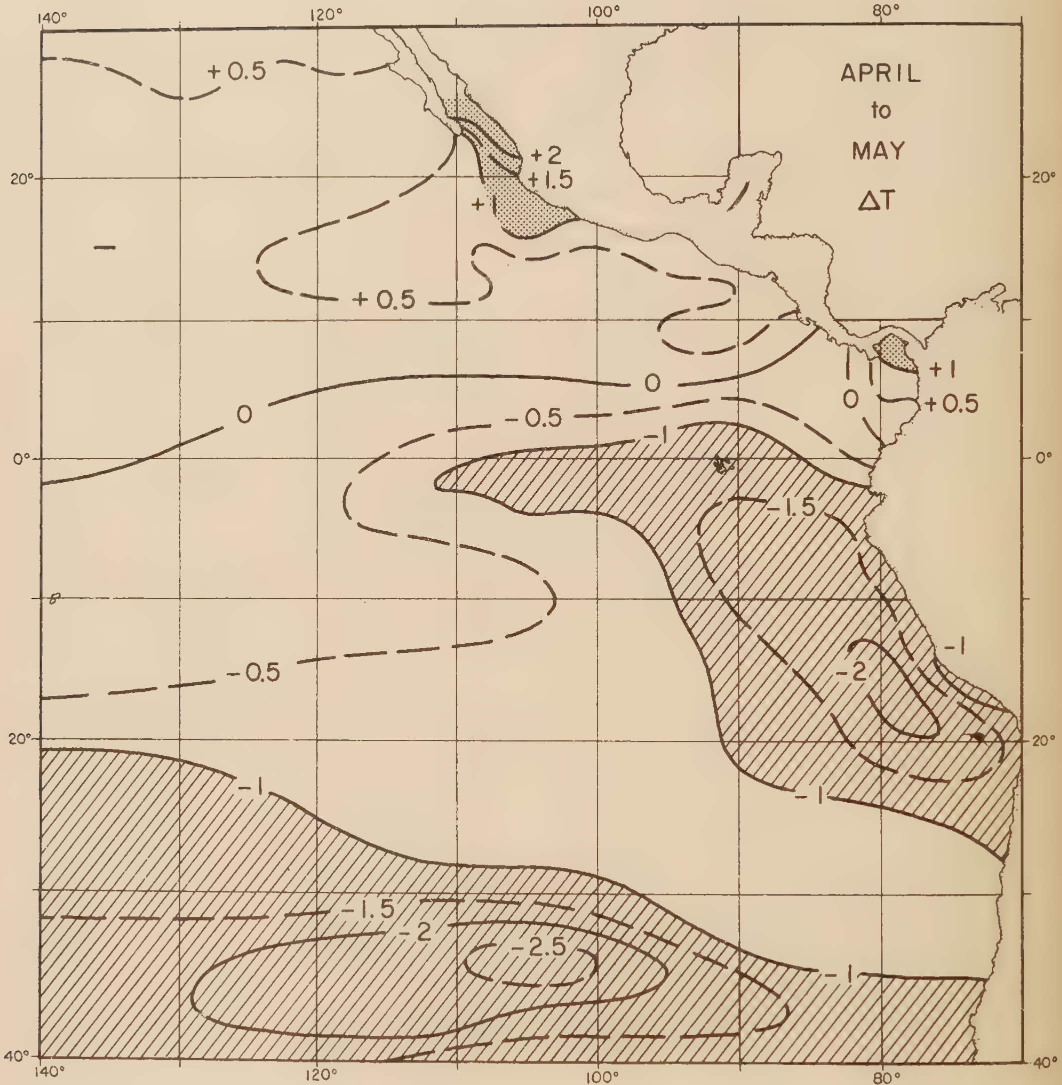

Fig. 17. Change of sea surface temperature from April to May in °C

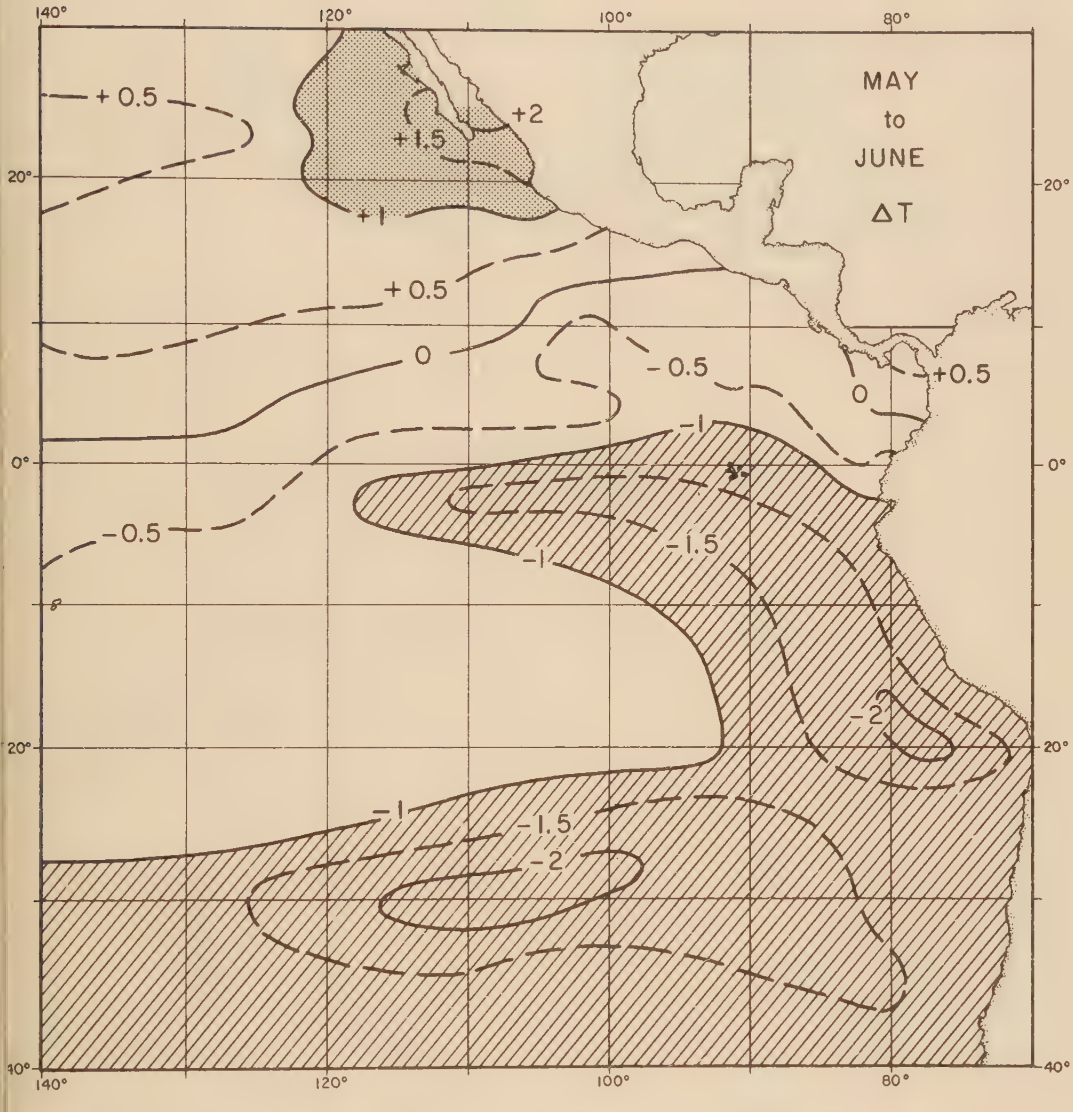

Fig.18. Change of sea surface temperature from May to June in °C

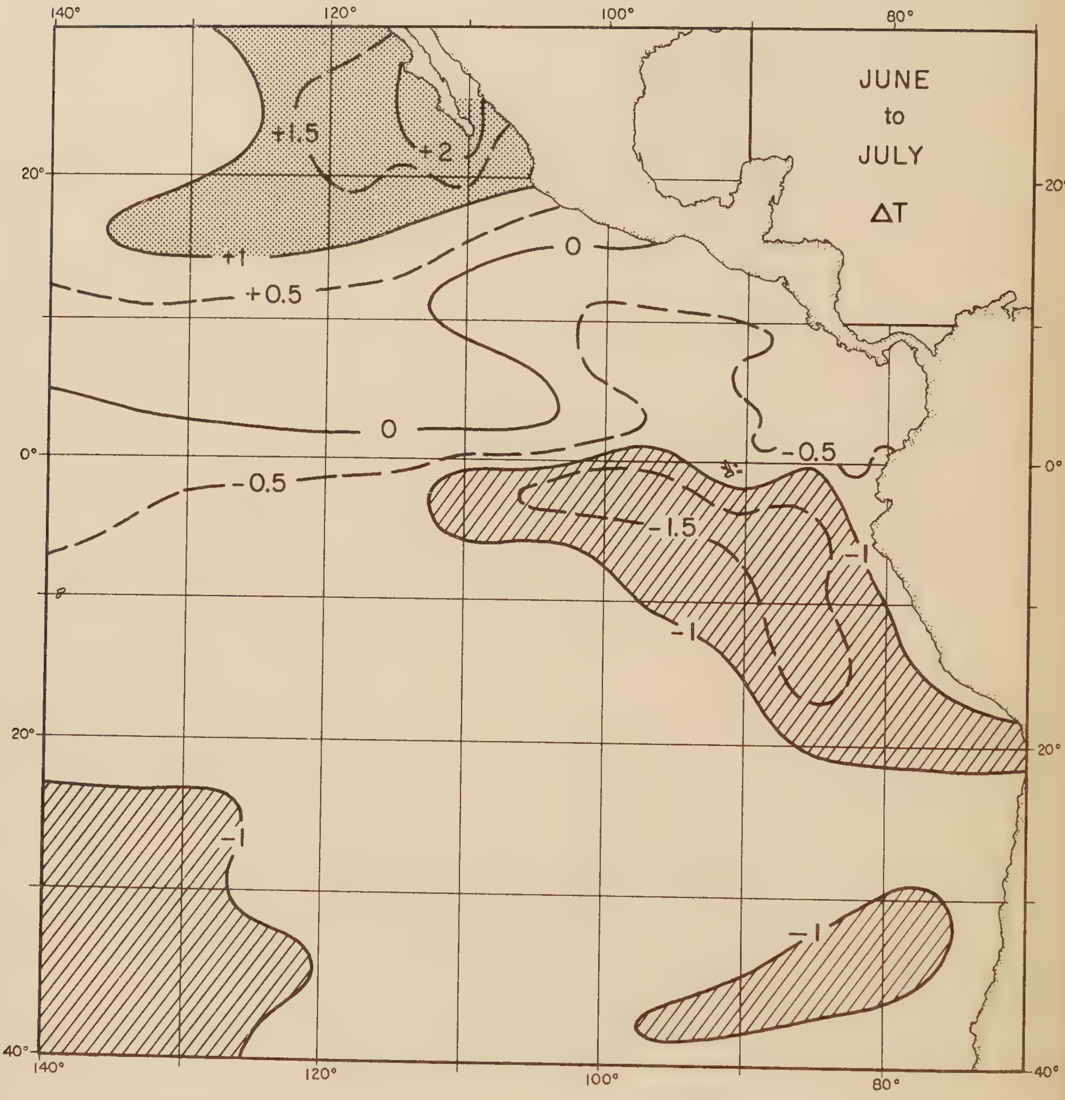

Fig. 19. Change of sea surface temperature from June to July in °C

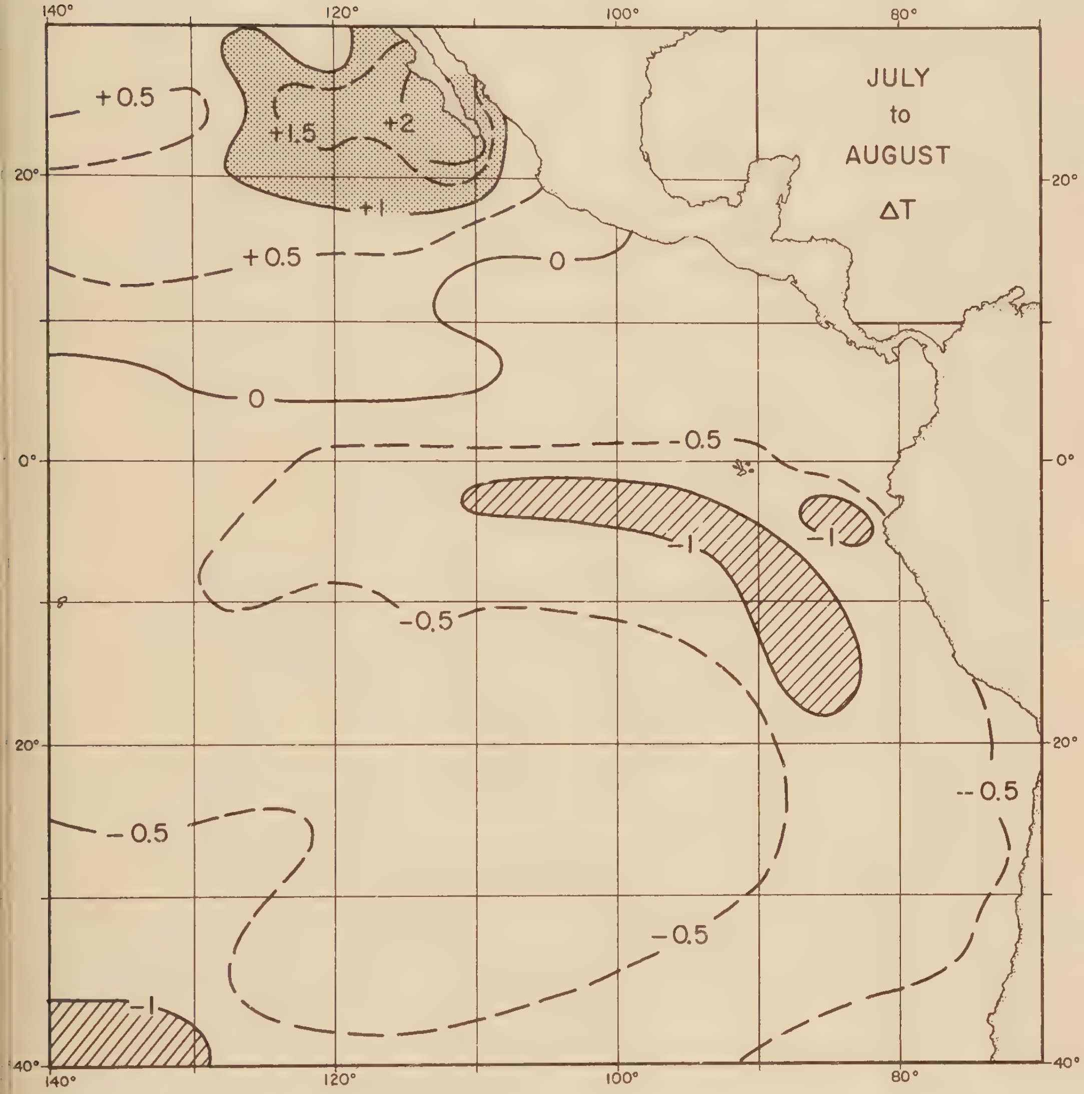

Fig. 20. Change of sea surface temperature from July to August in °C

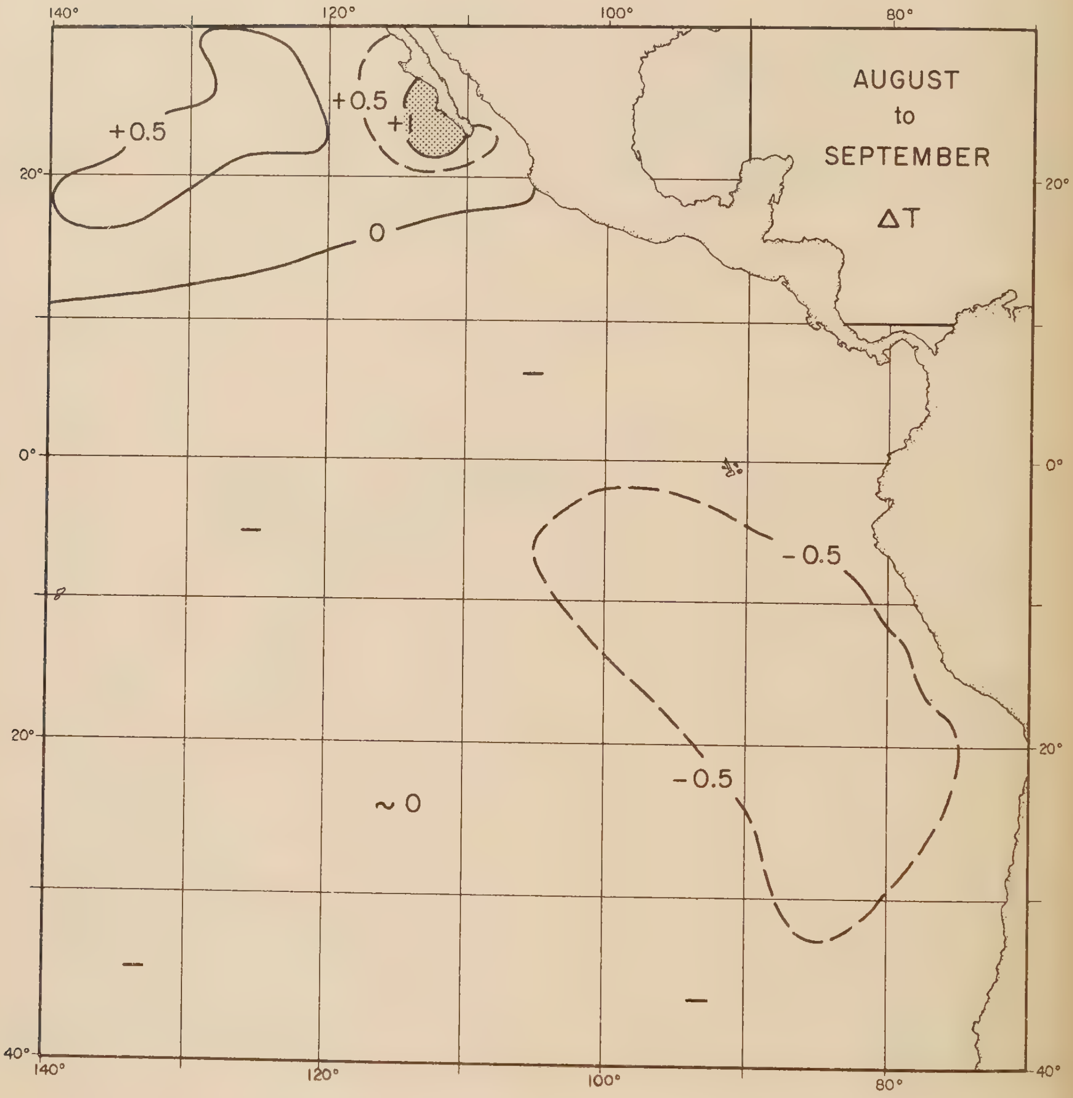

Fig. 21. Change of sea surface temperature from August to September in °C

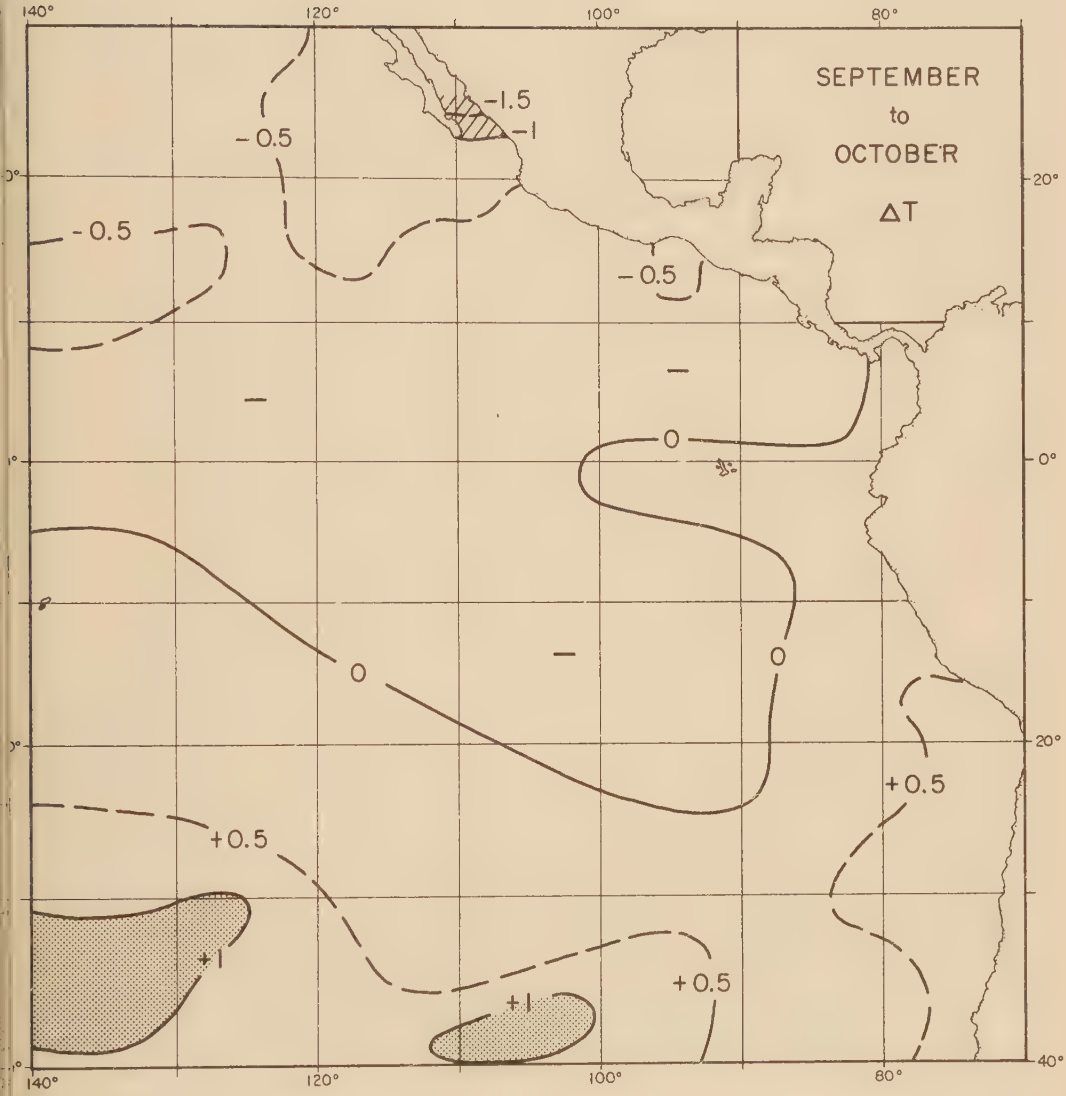

Fig. 22. Change of sea surface temperature from September to October in °C

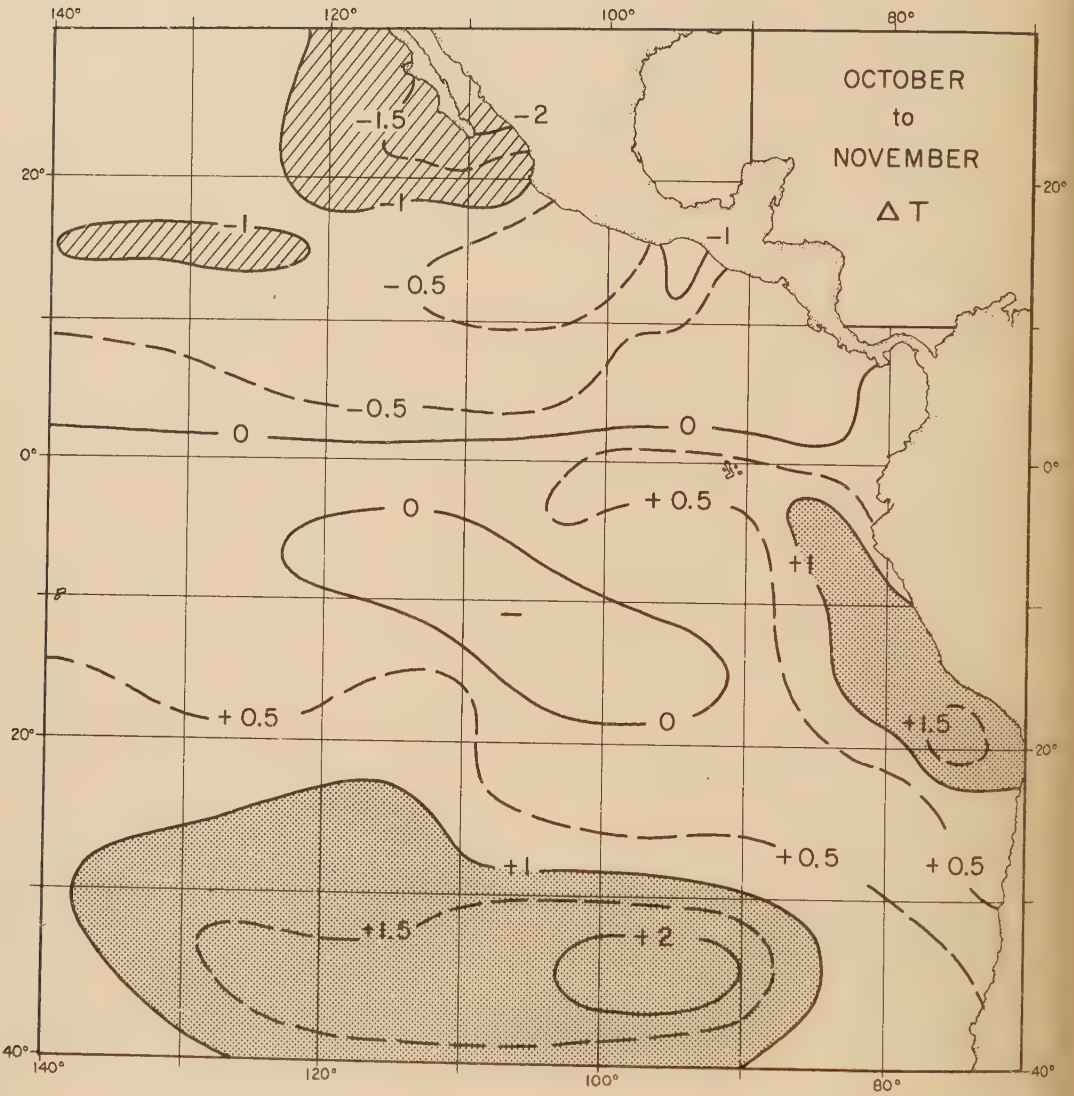

Fig. 23. Change of sea surface temperature from October to November in °C

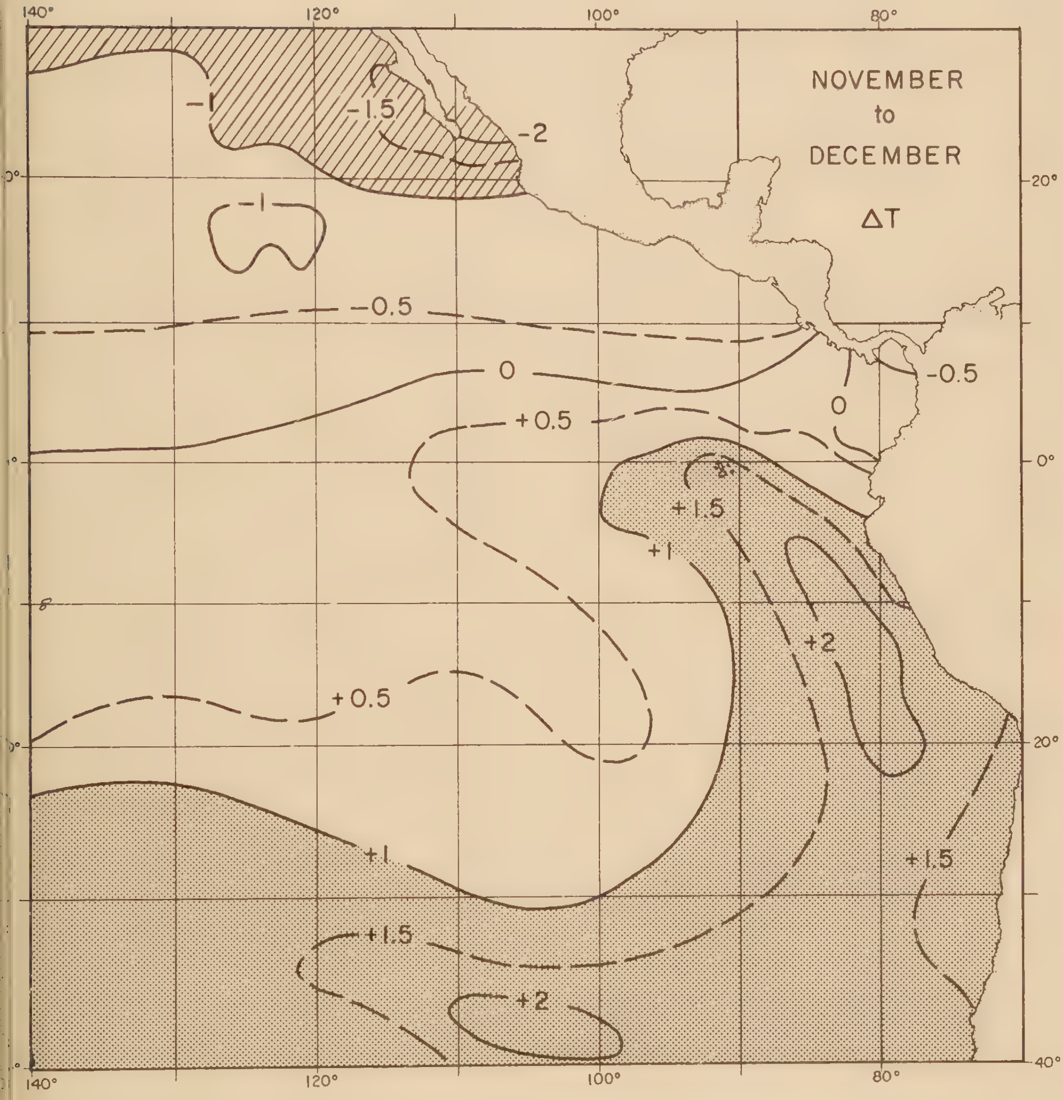

Fig. 24. Change of sea surface temperature from November to December in °C

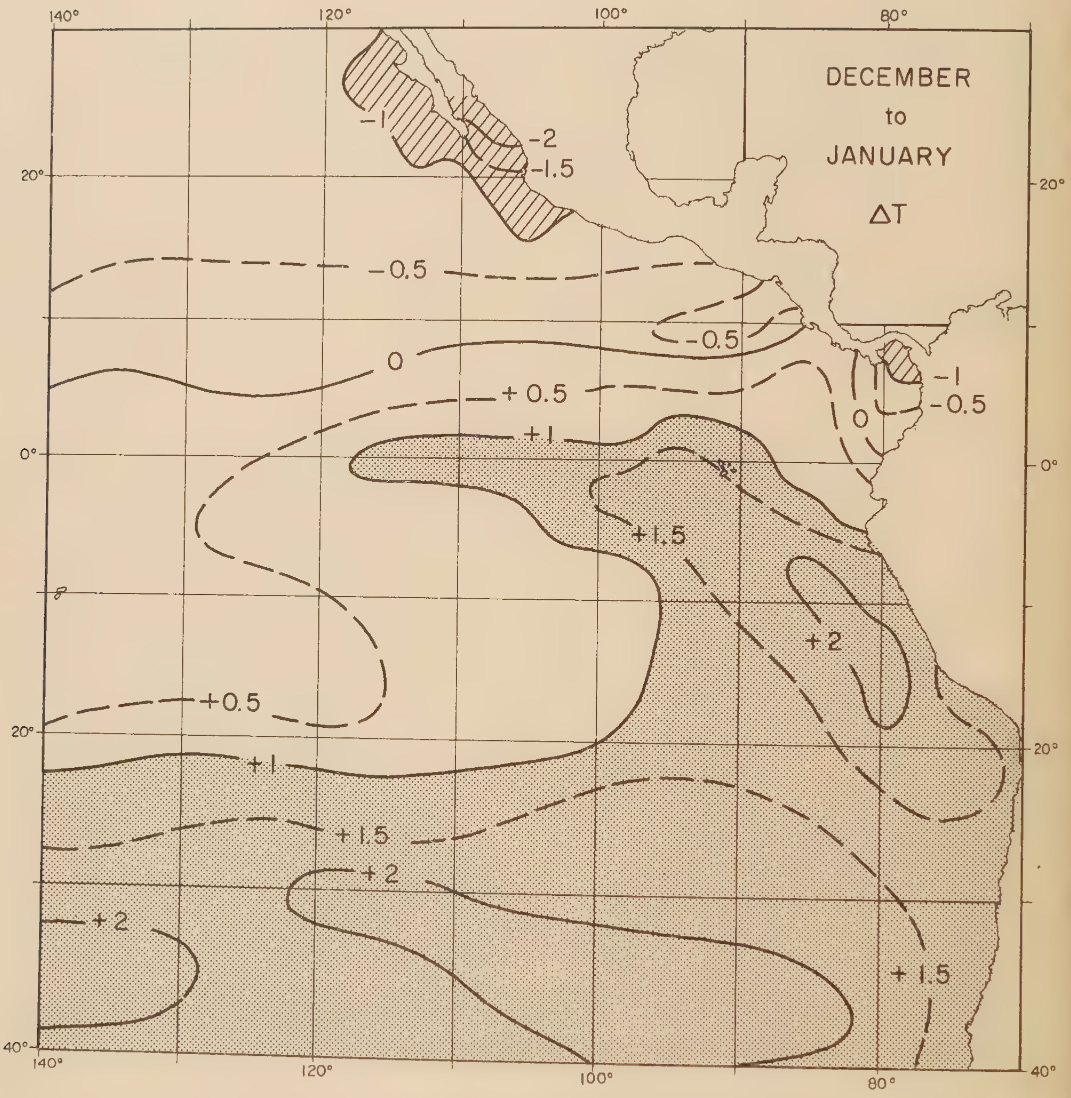

Fig. 25. Change of sea surface temperature from December to January in °C

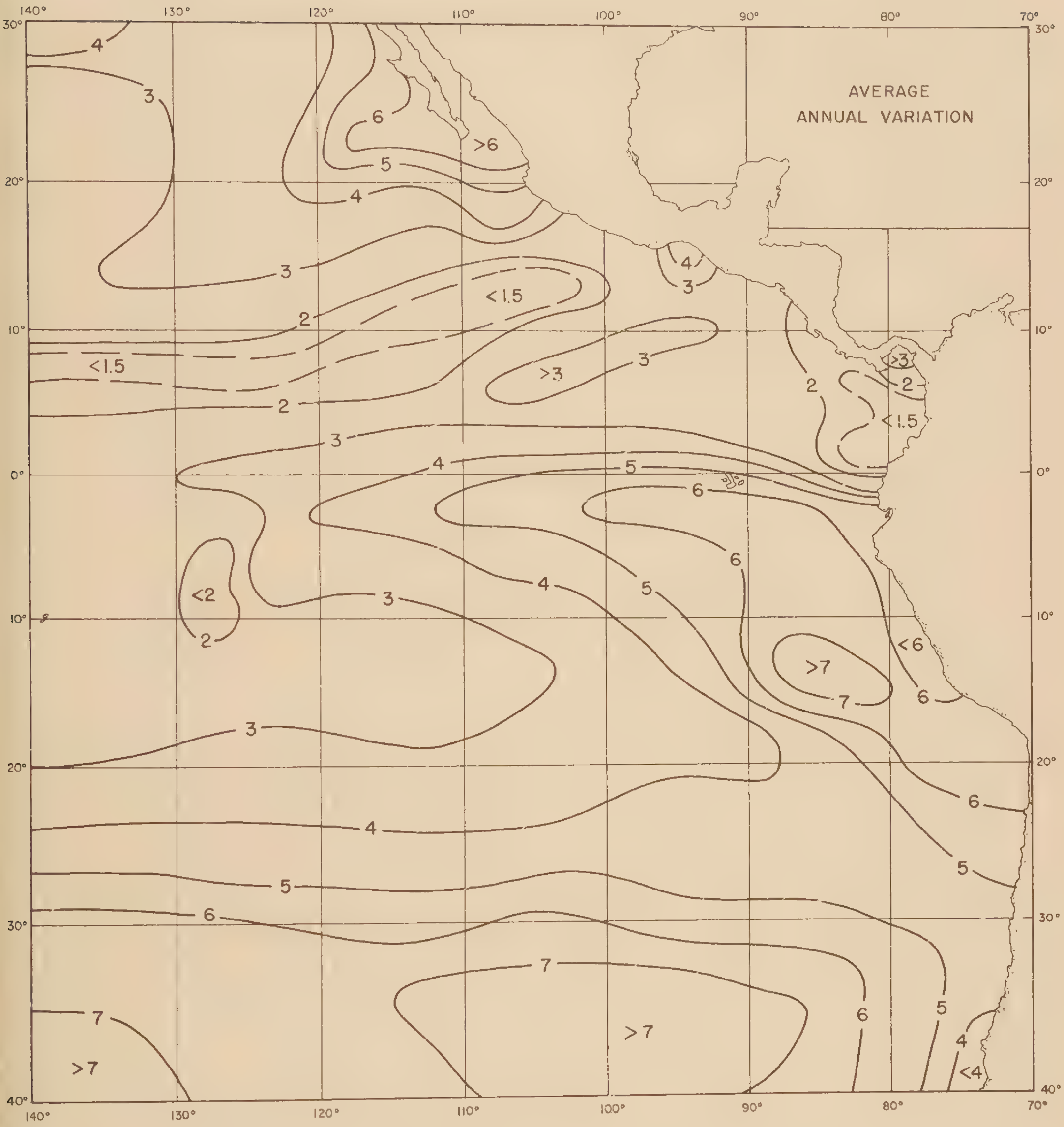

Fig. 26. Average annual variation of sea surface temperature in °C
(Highest minus lowest monthly average)

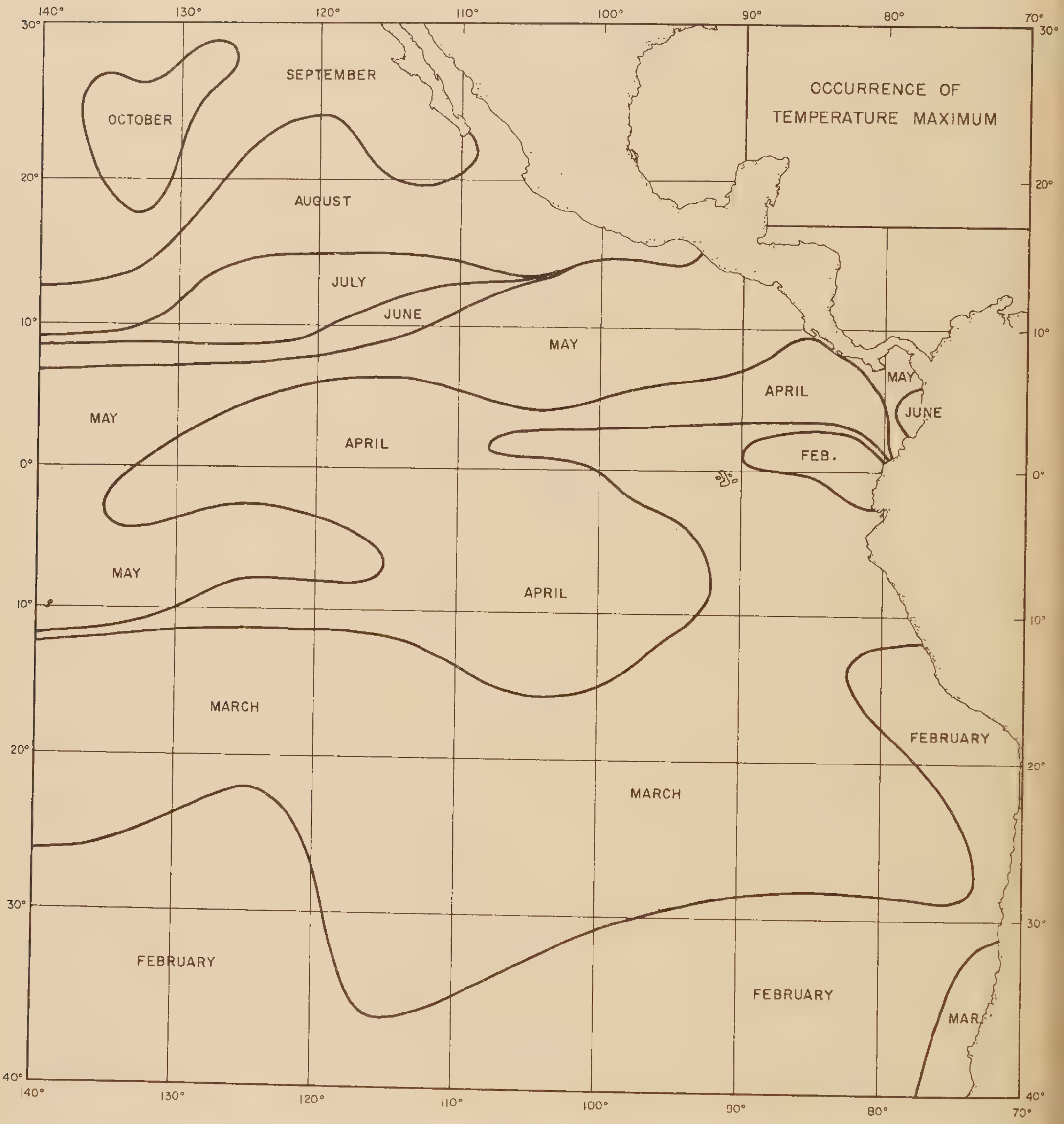

Fig. 27. Occurrence of the temperature maximum at the sea surface

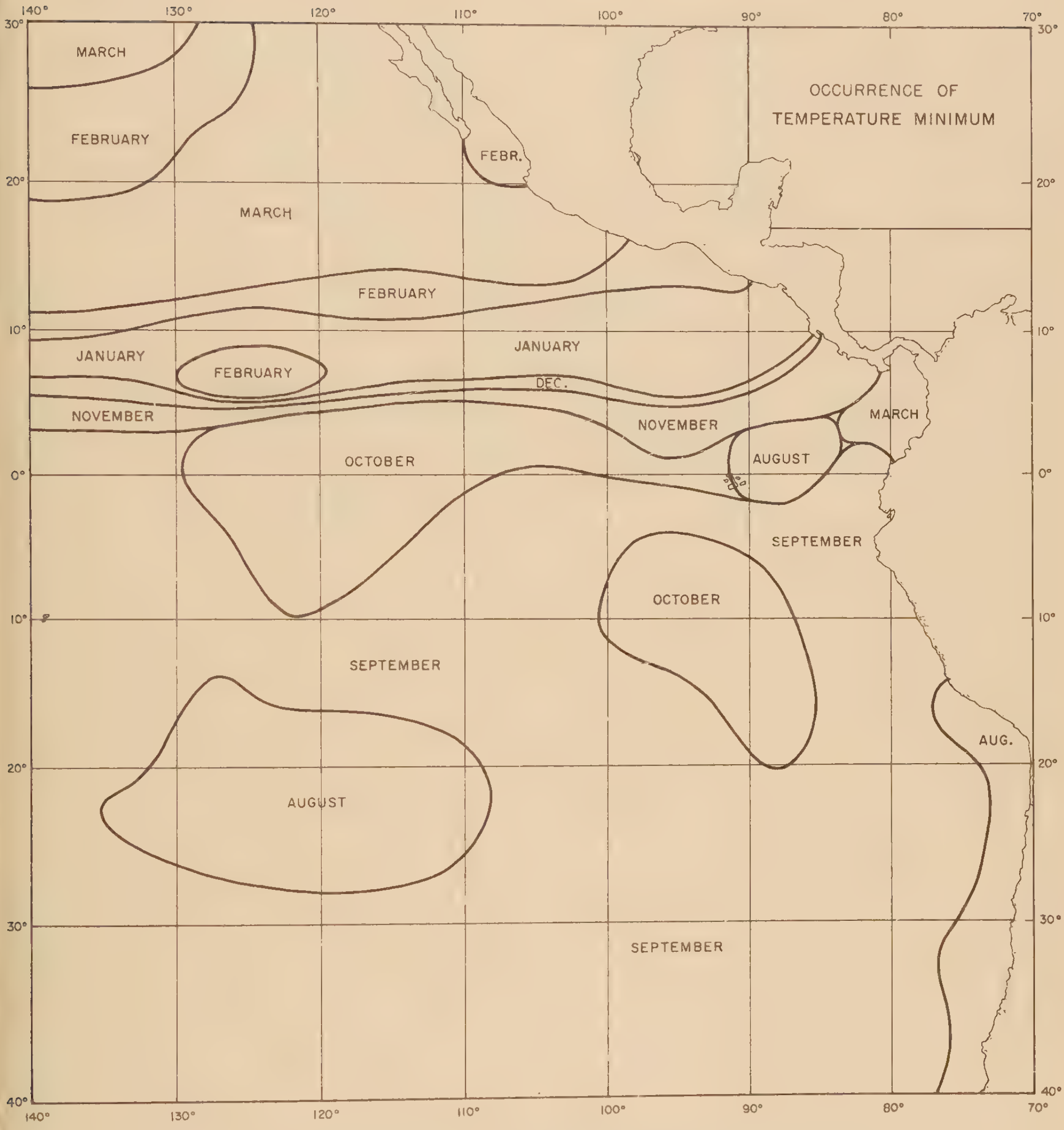

Fig. 28. Occurrence of the temperature minimum at the sea surface

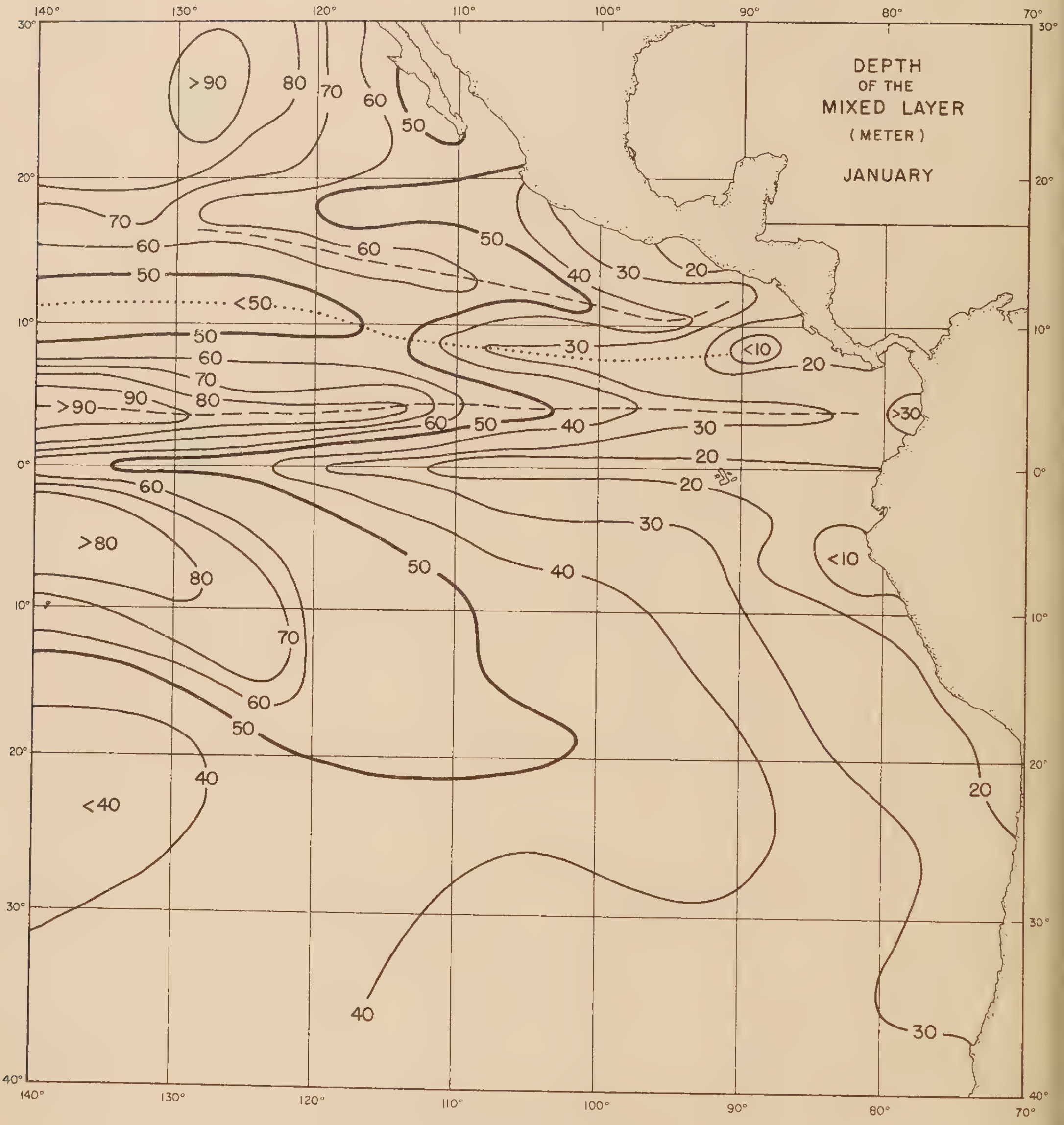

Fig. 29. Depth of the mixed layer in meters for January.
Dotted line indicates a ridge, broken line a trough

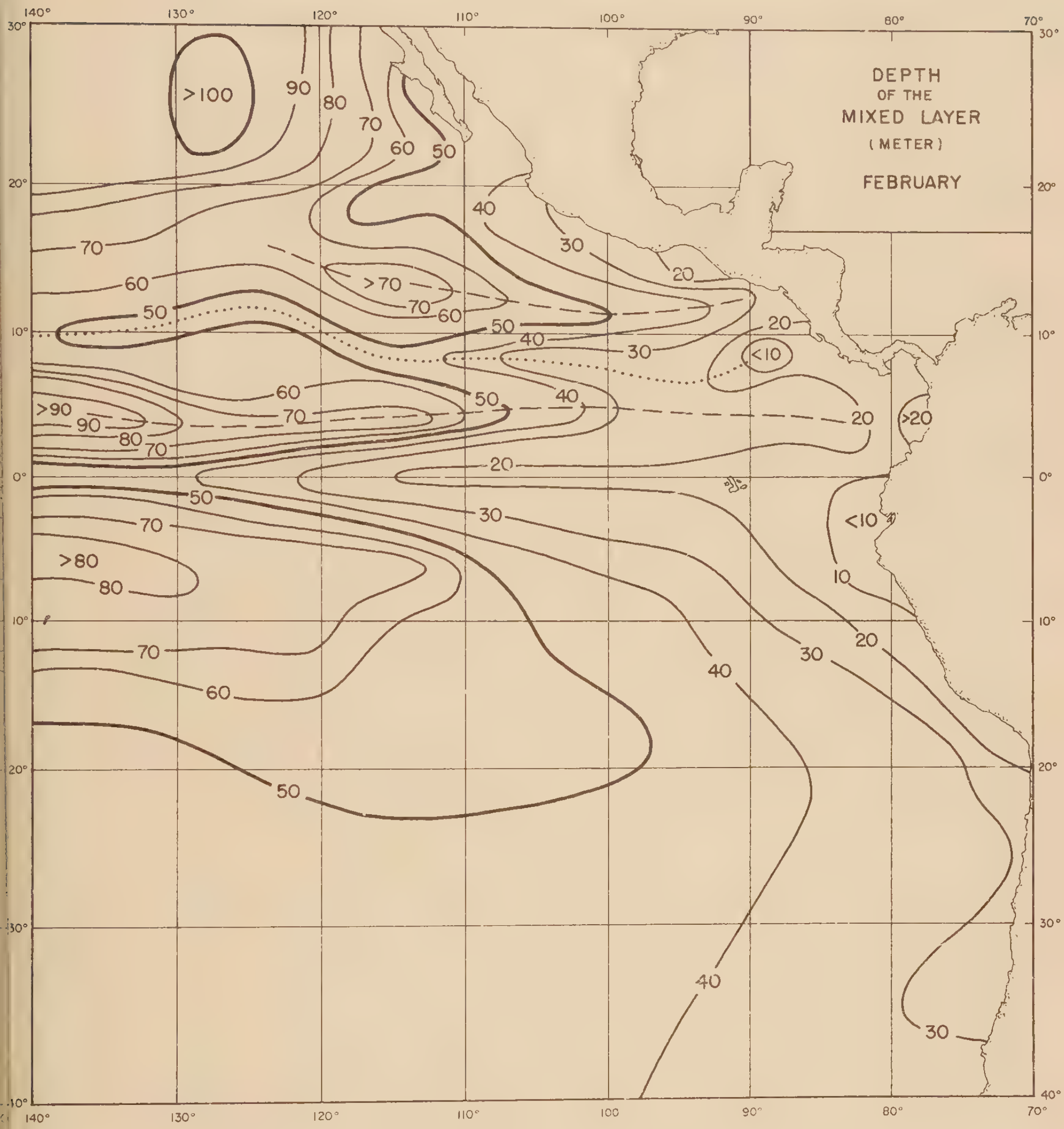

Fig. 30. Depth of the mixed layer in meters for February. Dotted line indicates a ridge, broken line a trough

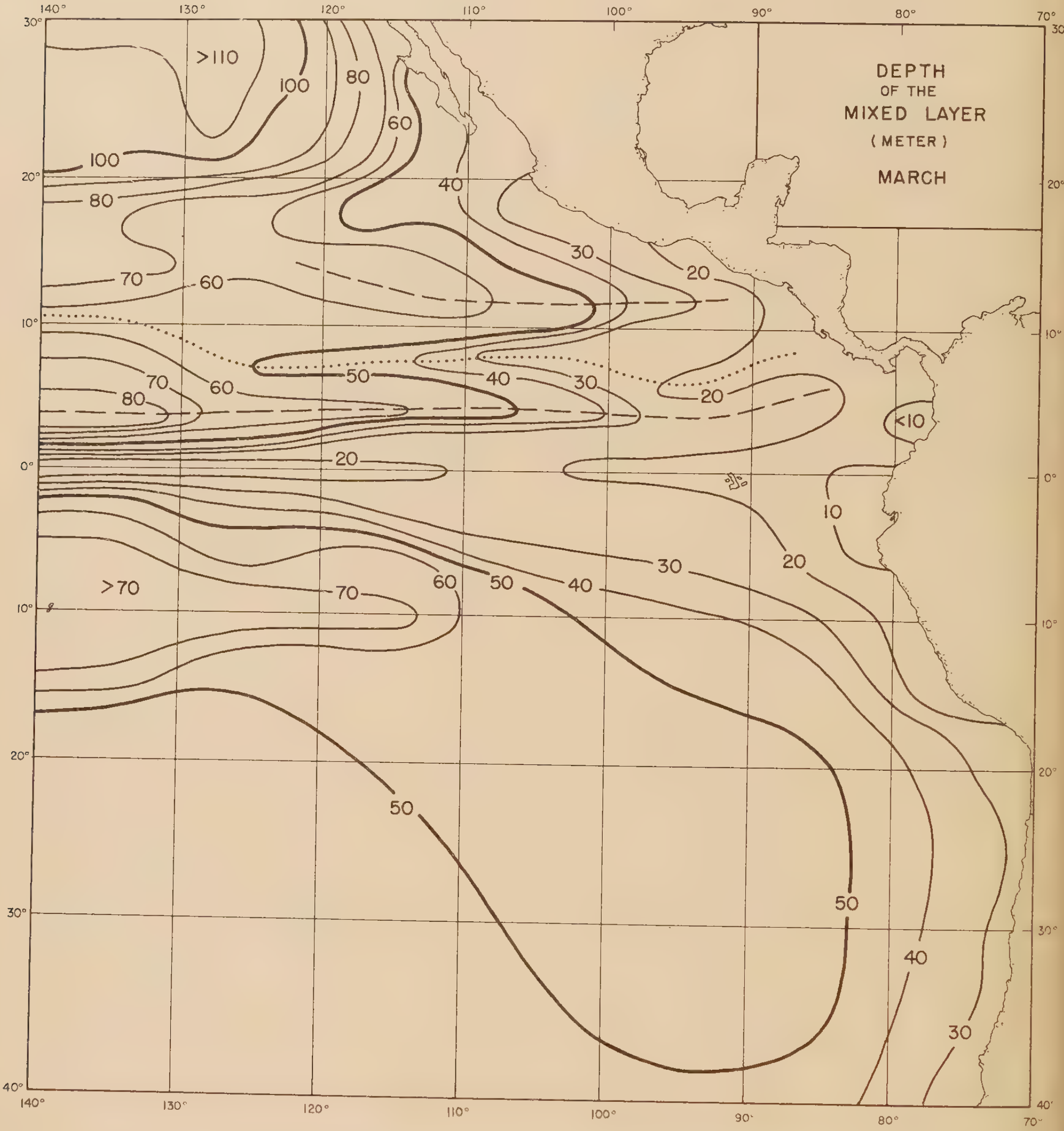

Fig. 31. Depth of the mixed layer in meters for March.
Dotted line indicates a ridge, broken line a trough

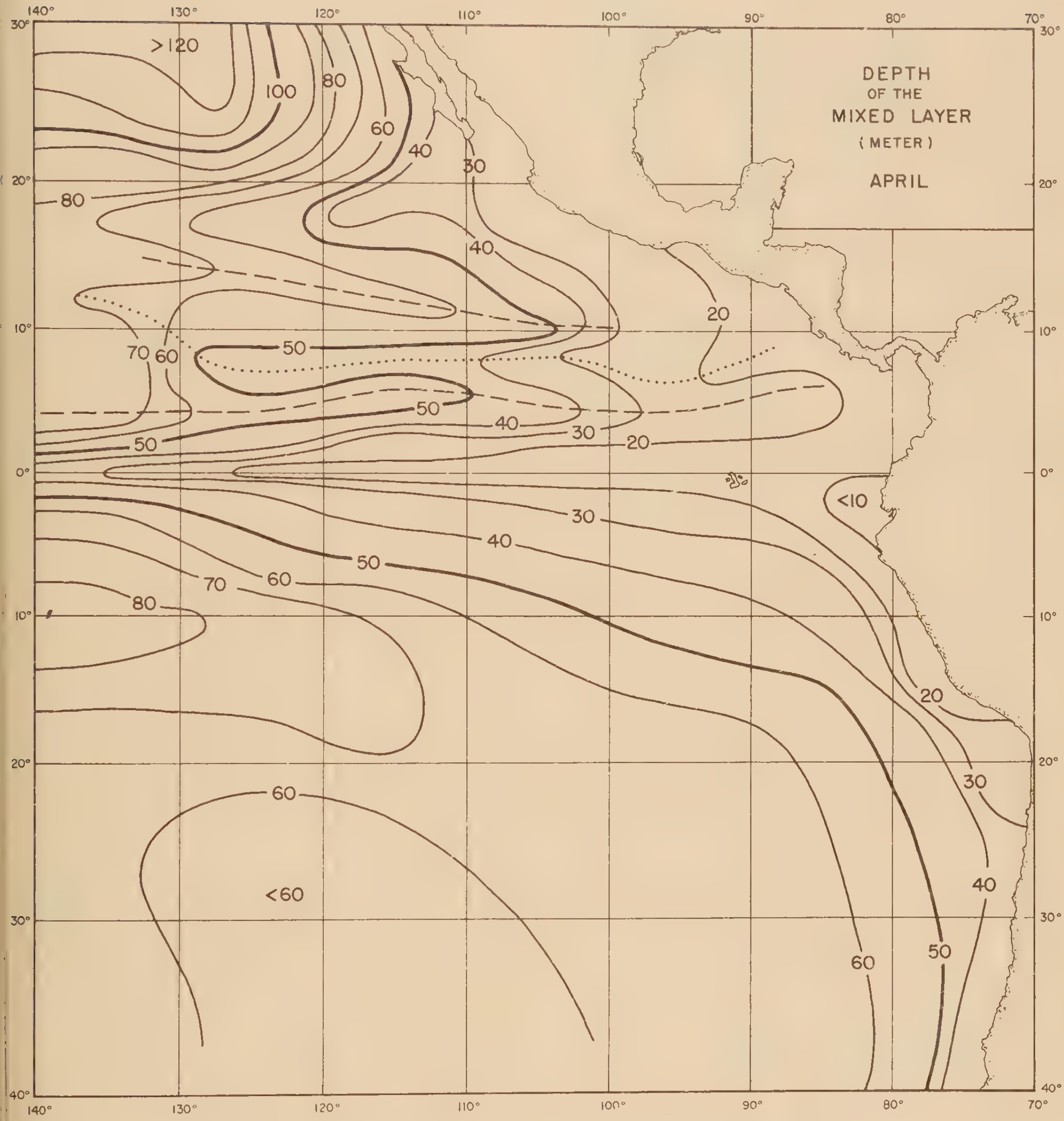

Fig. 32. Depth of the mixed layer in meters for April.
Dotted line indicates a ridge, broken line a trough

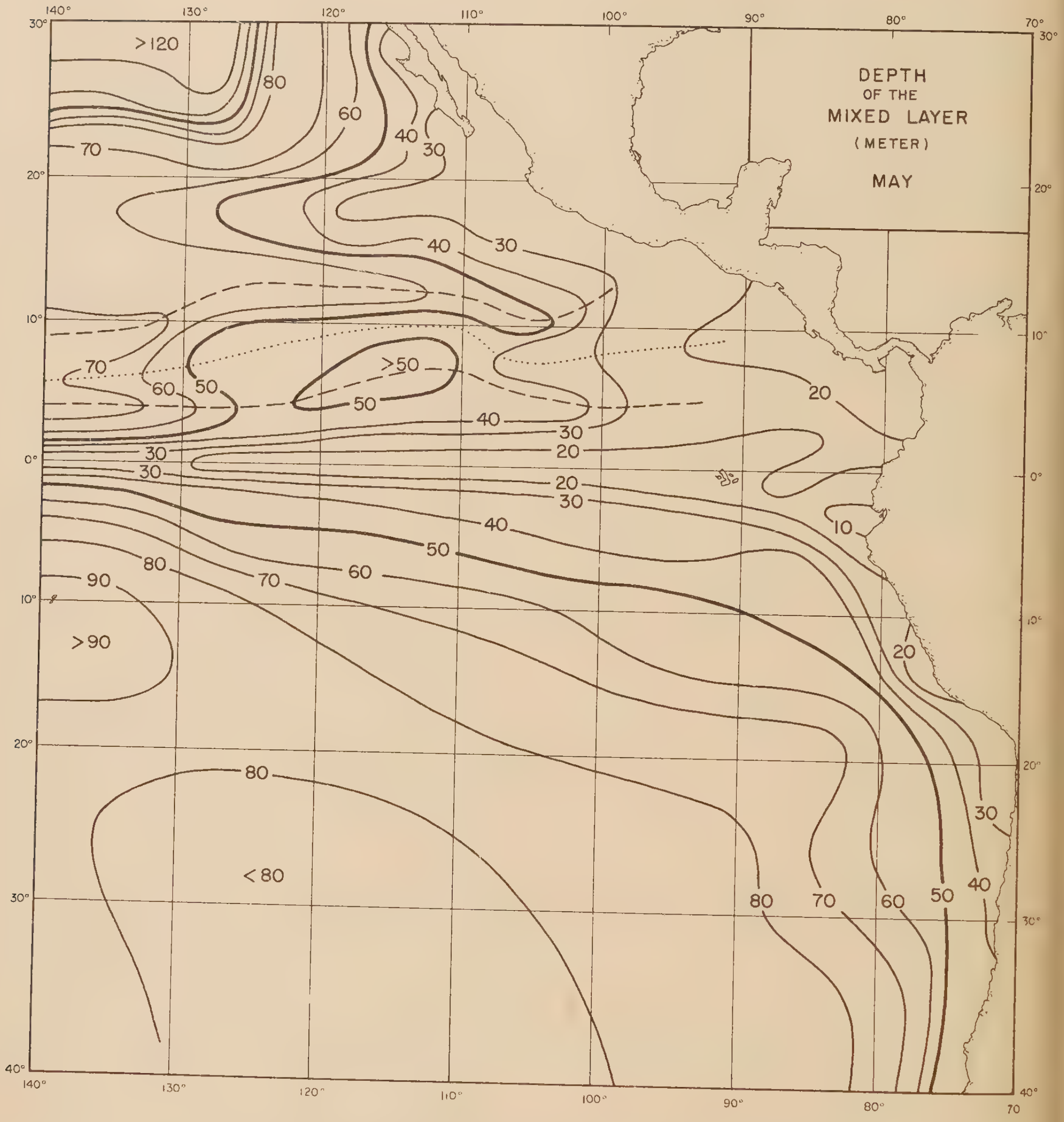

Fig. 33. Depth of the mixed layer in meters for May. Dotted line indicates a ridge, broken line a trough

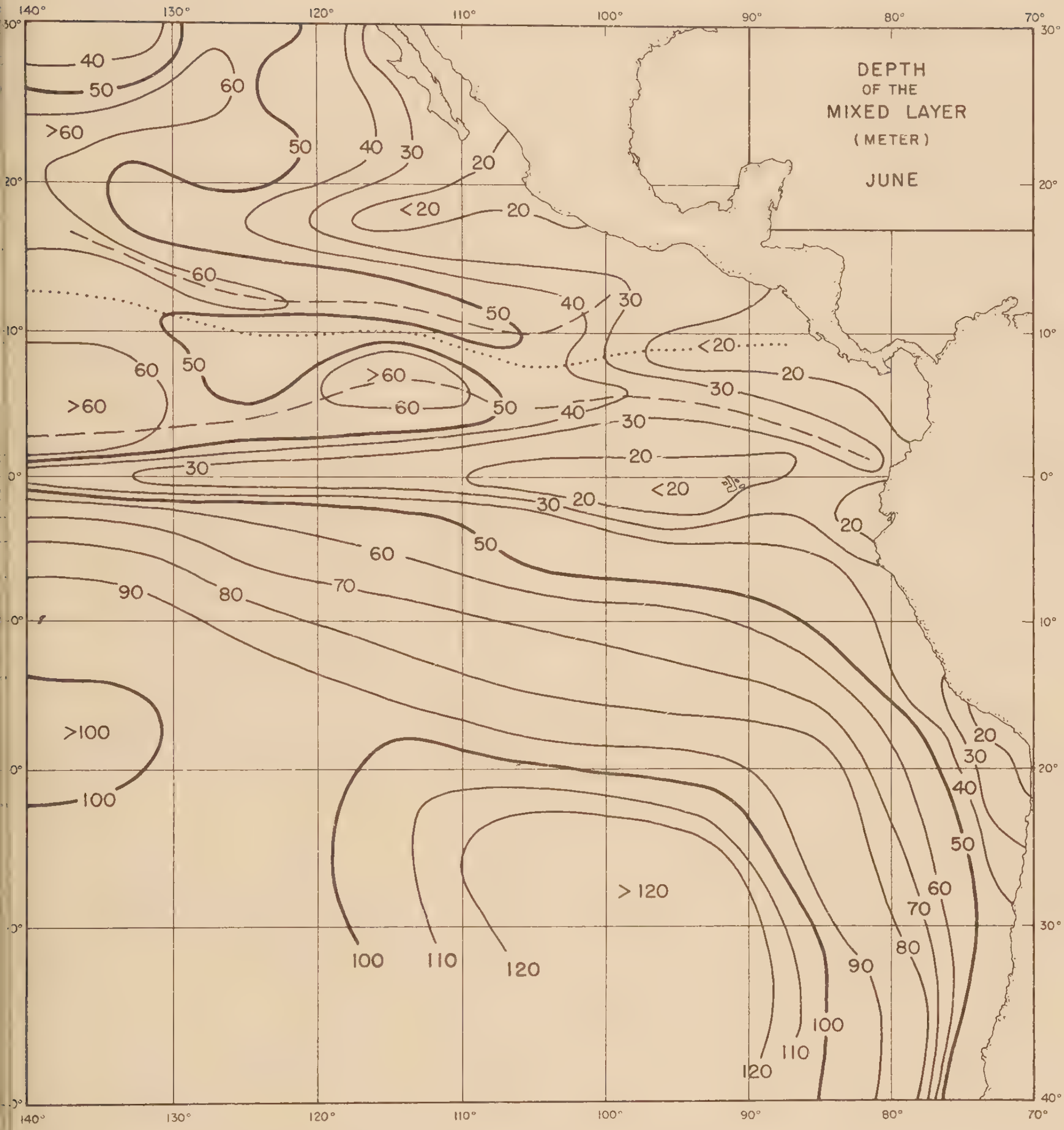

Fig. 34. Depth of the mixed layer in meters for June.
Dotted line indicates a ridge, broken line a trough

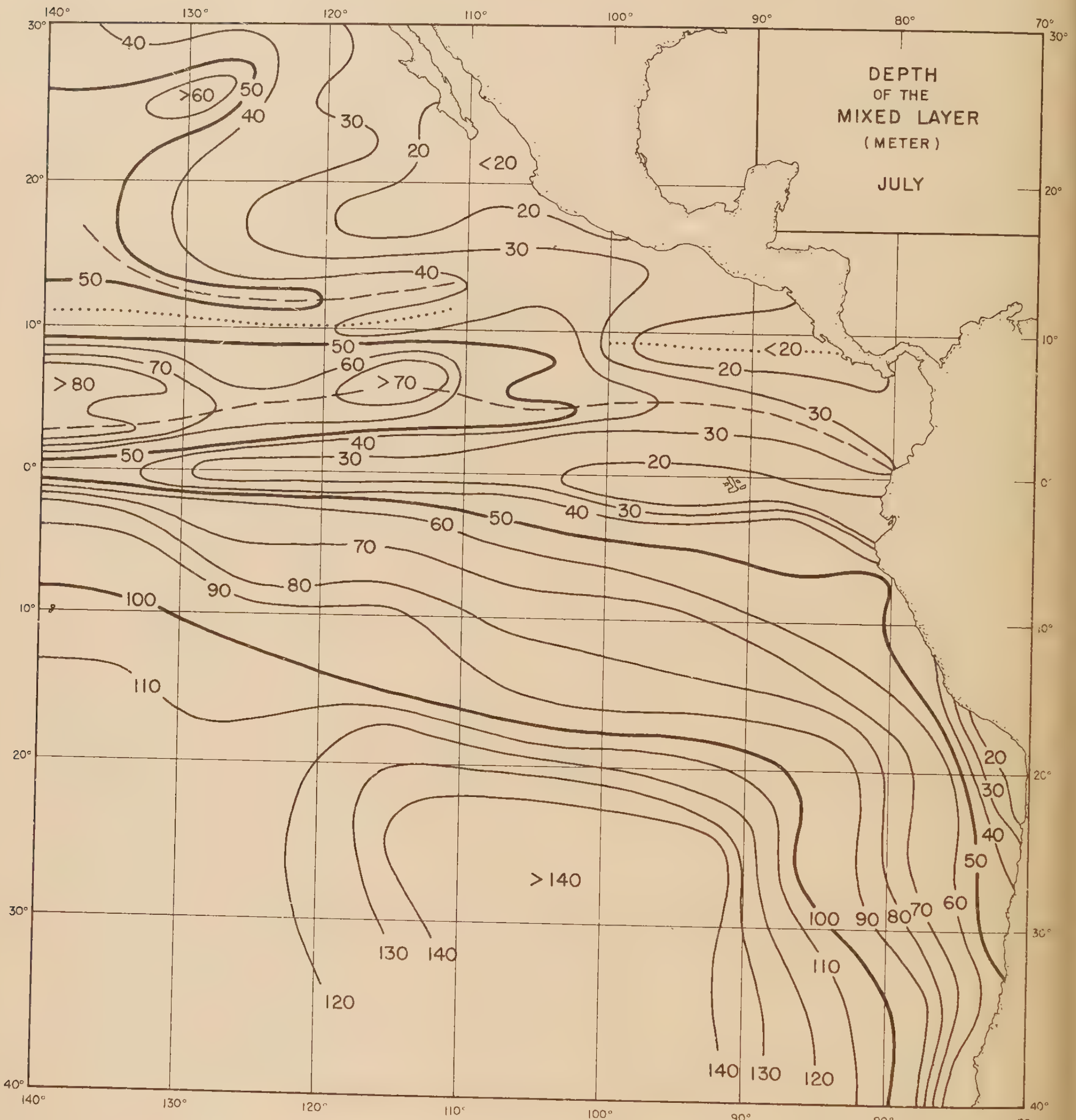

Fig. 35. Depth of the mixed layer in meters for July. Dotted line indicates a ridge, broken line a trough

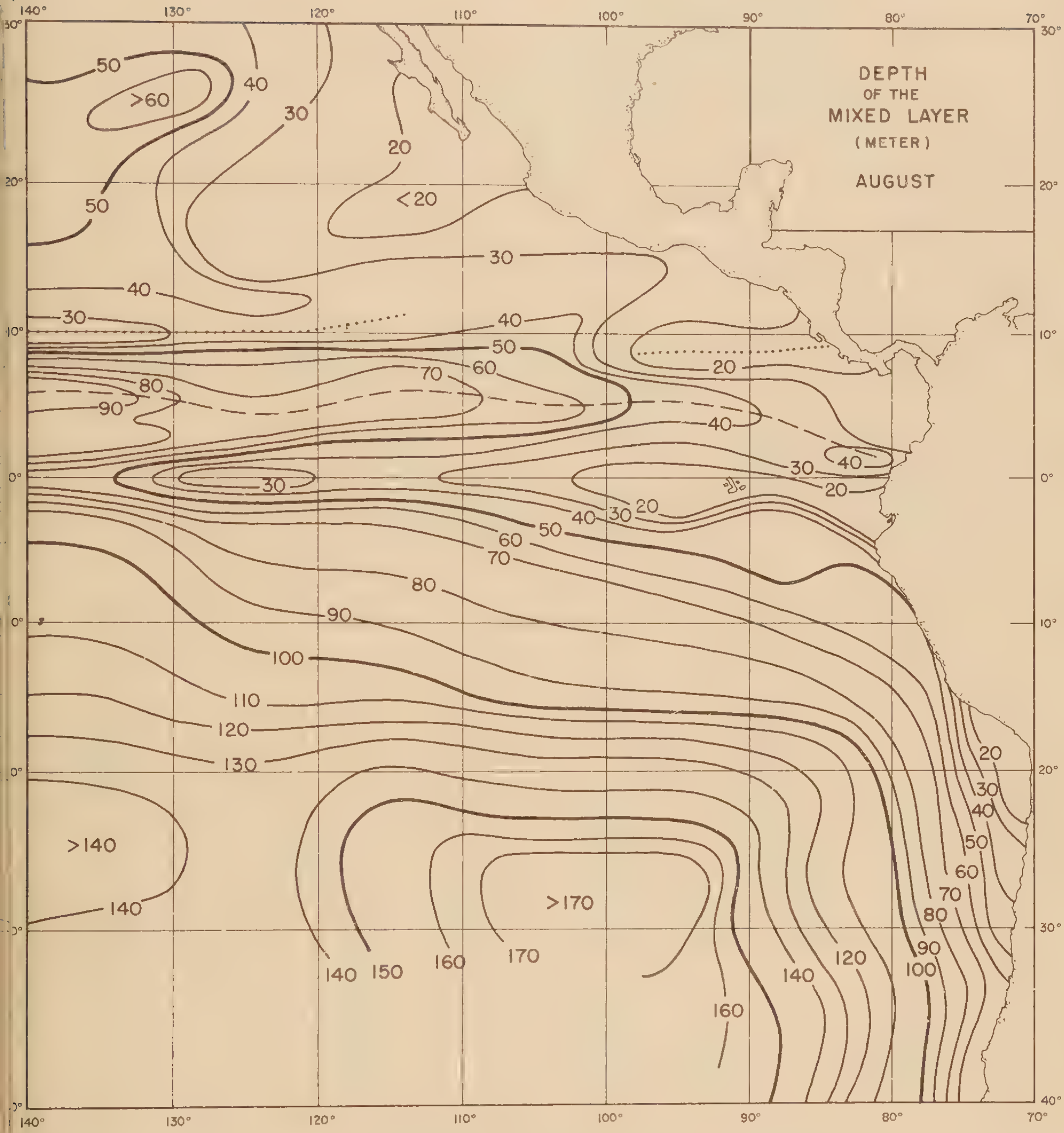

Fig. 36. Depth of the mixed layer in meters for August.
Dotted line indicates a ridge, broken line a trough

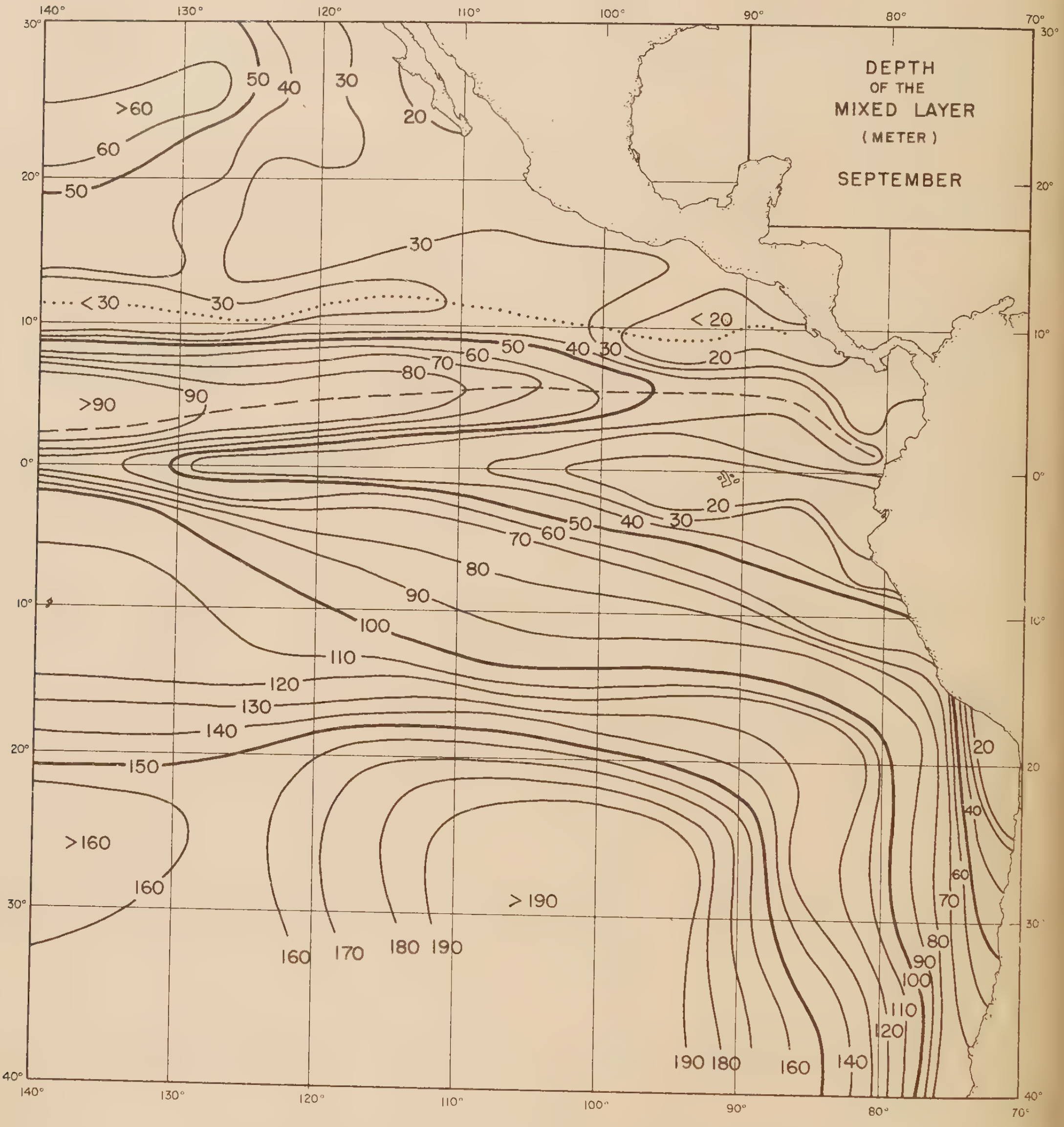

Fig. 37. Depth of the mixed layer in meters for September.
Dotted line indicates a ridge, broken line a trough

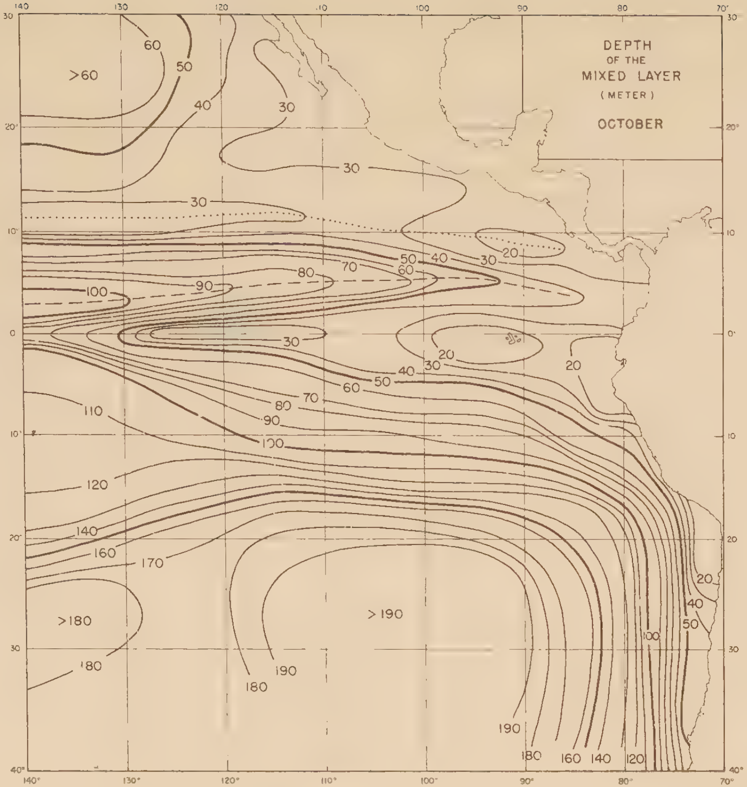

Fig: 38. Depth of the mixed layer in meters for October. Dotted line indicates a ridge, broken line a trough

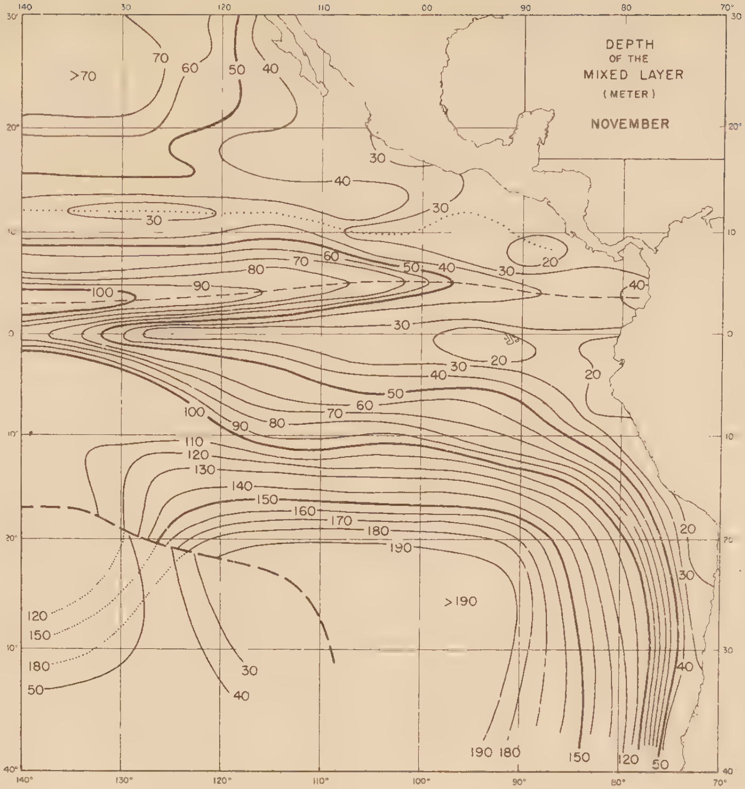

Fig. 39. Depth of the mixed layer in meters for November. Dotted line indicates a ridge, broken line a trough. Heavy broken line indicates the extent of the shallow mixed layer above the new summer thermocline

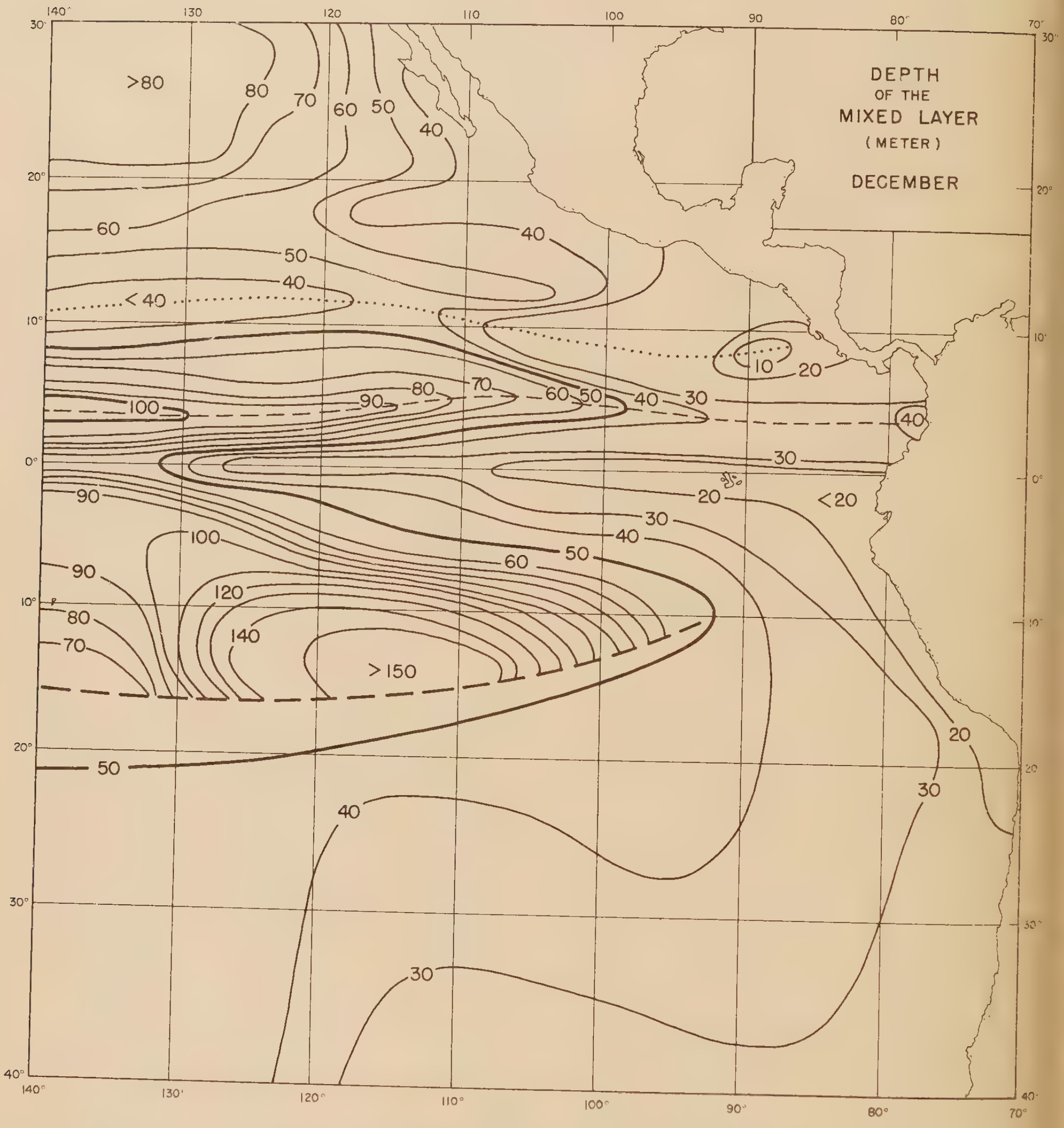

Fig. 40. Depth of the mixed layer in meters for December
Dotted line indicates a ridge, broken line a trough. Heavy broken line indicates the extent of the shallow mixed layer above the new summer thermocline

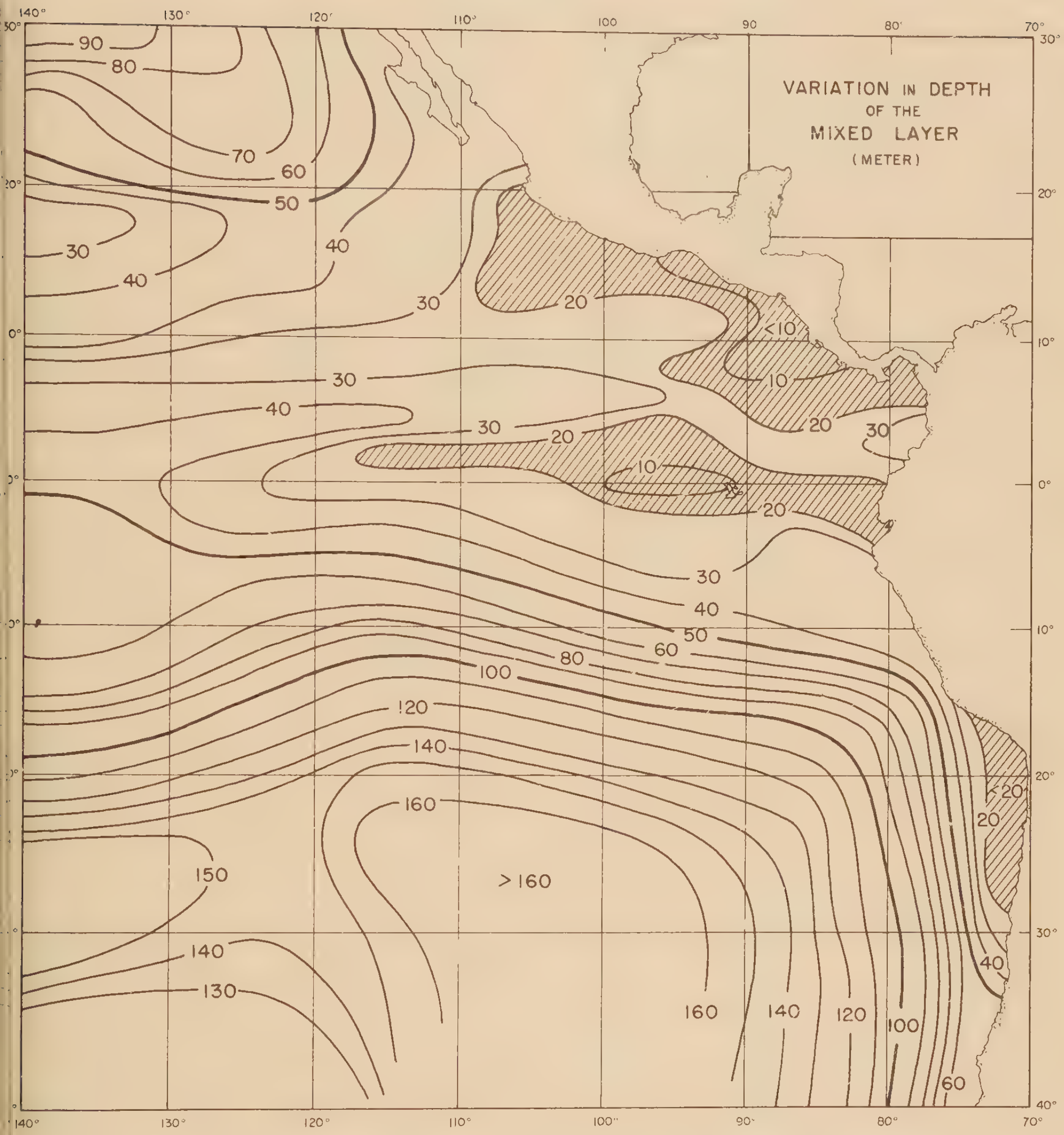

Fig. 41. Variation of the depth of the mixed layer in meters. < 20 meters hatched

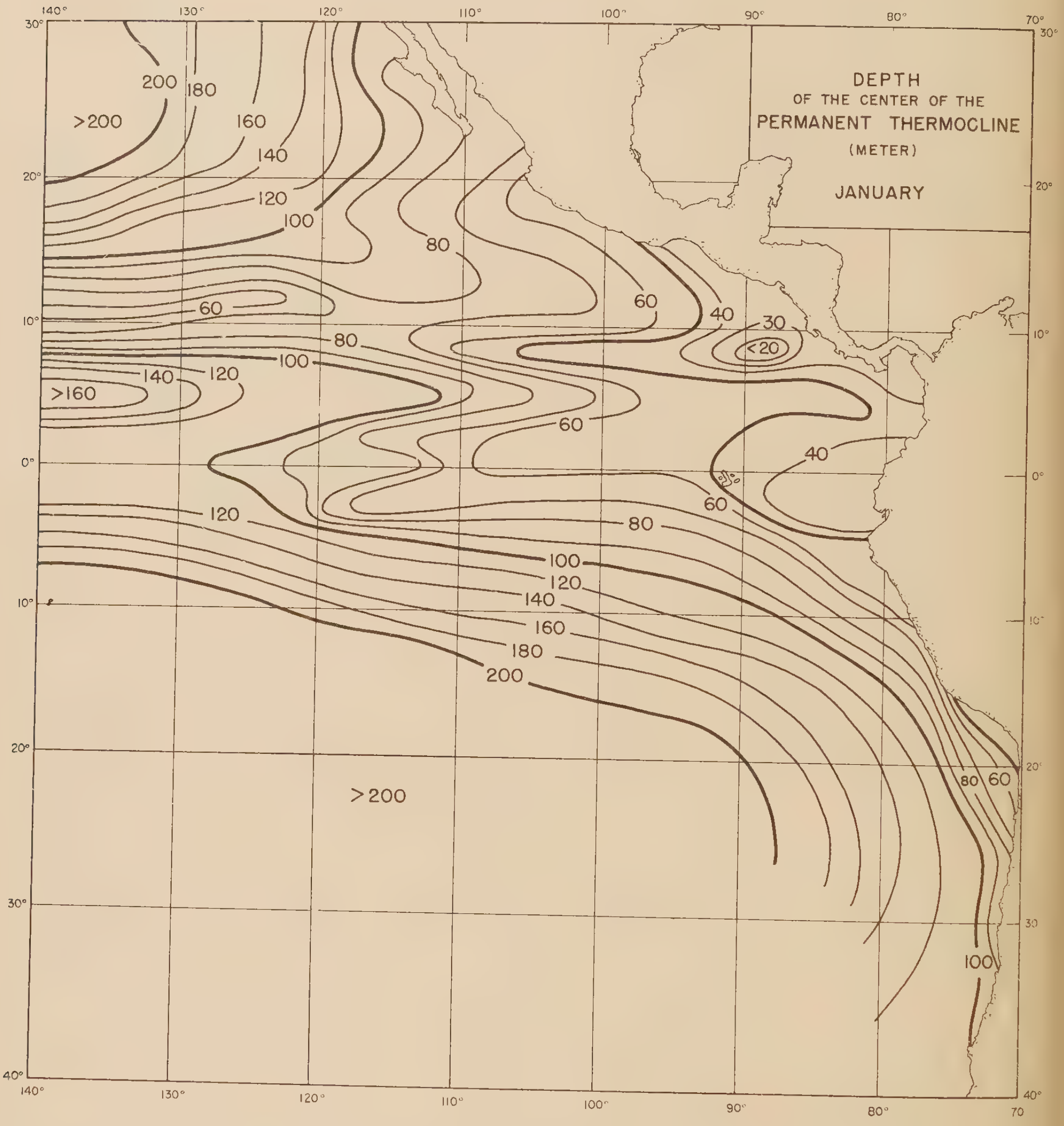

Fig. 42. Depth of the centre of the permanent thermocline in meters in January

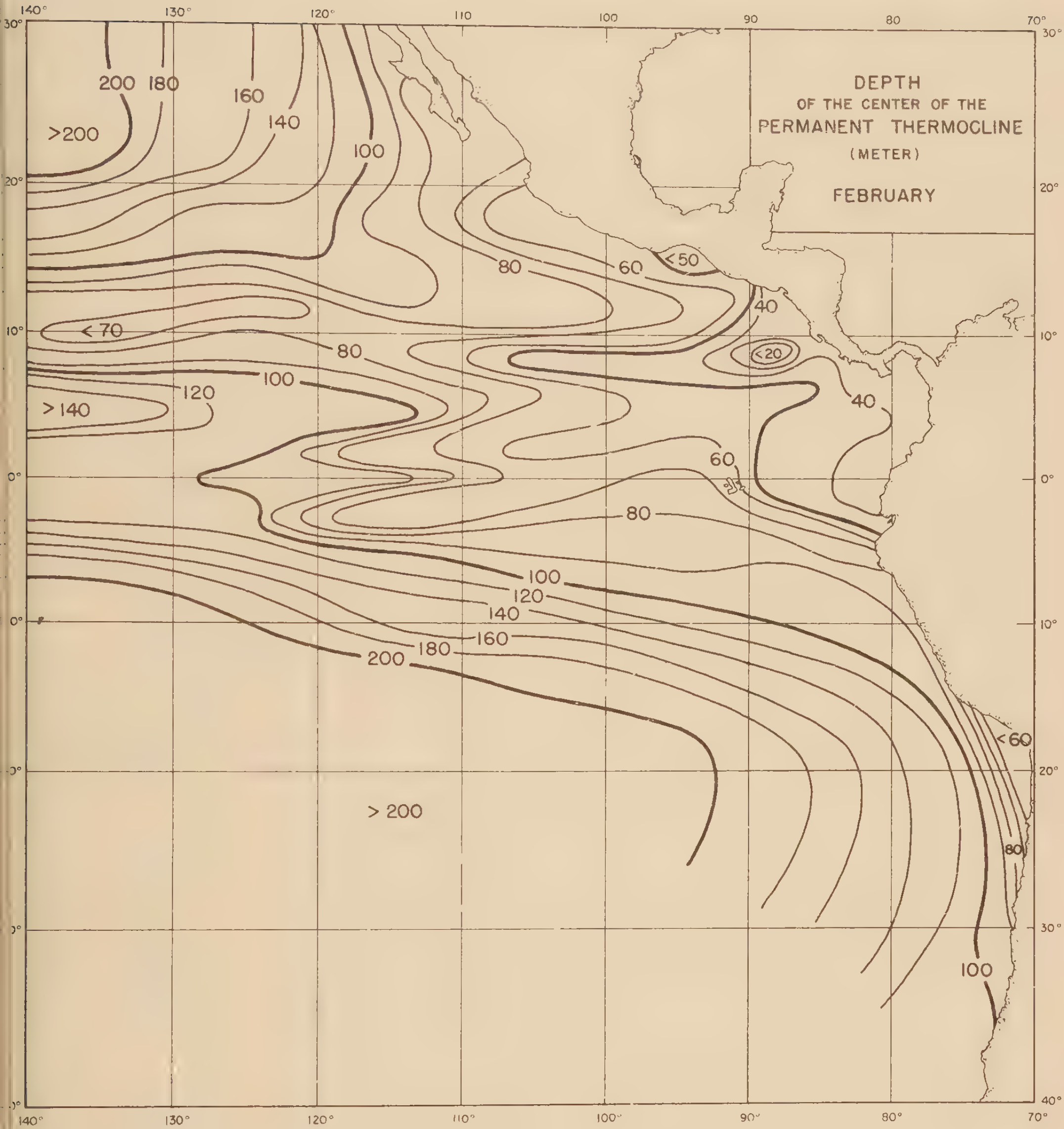

Fig. 43. Depth of the centre of the permanent thermocline in meters in February

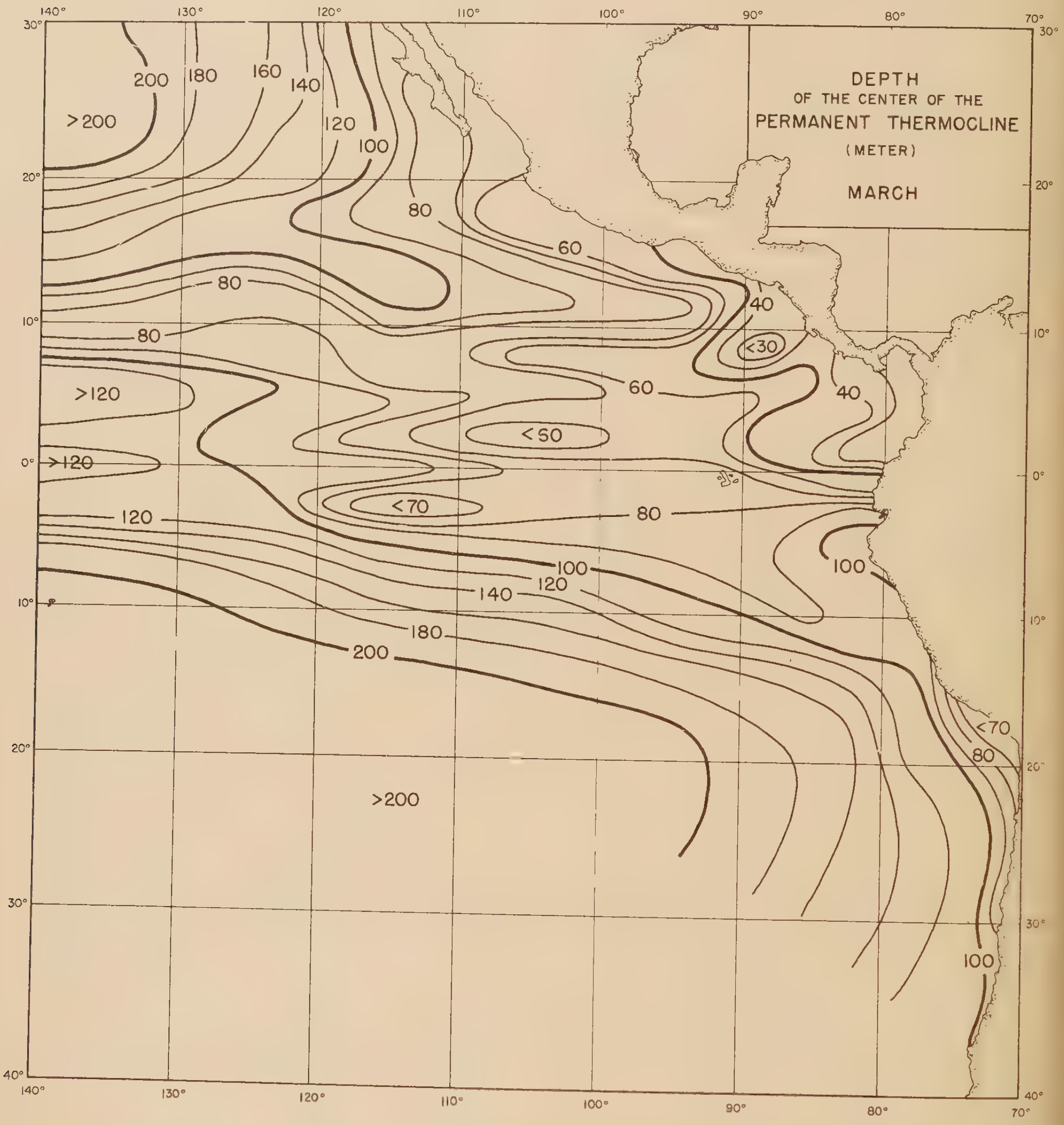

Fig. 44. Depth of the centre of the permanent thermocline in meters in March

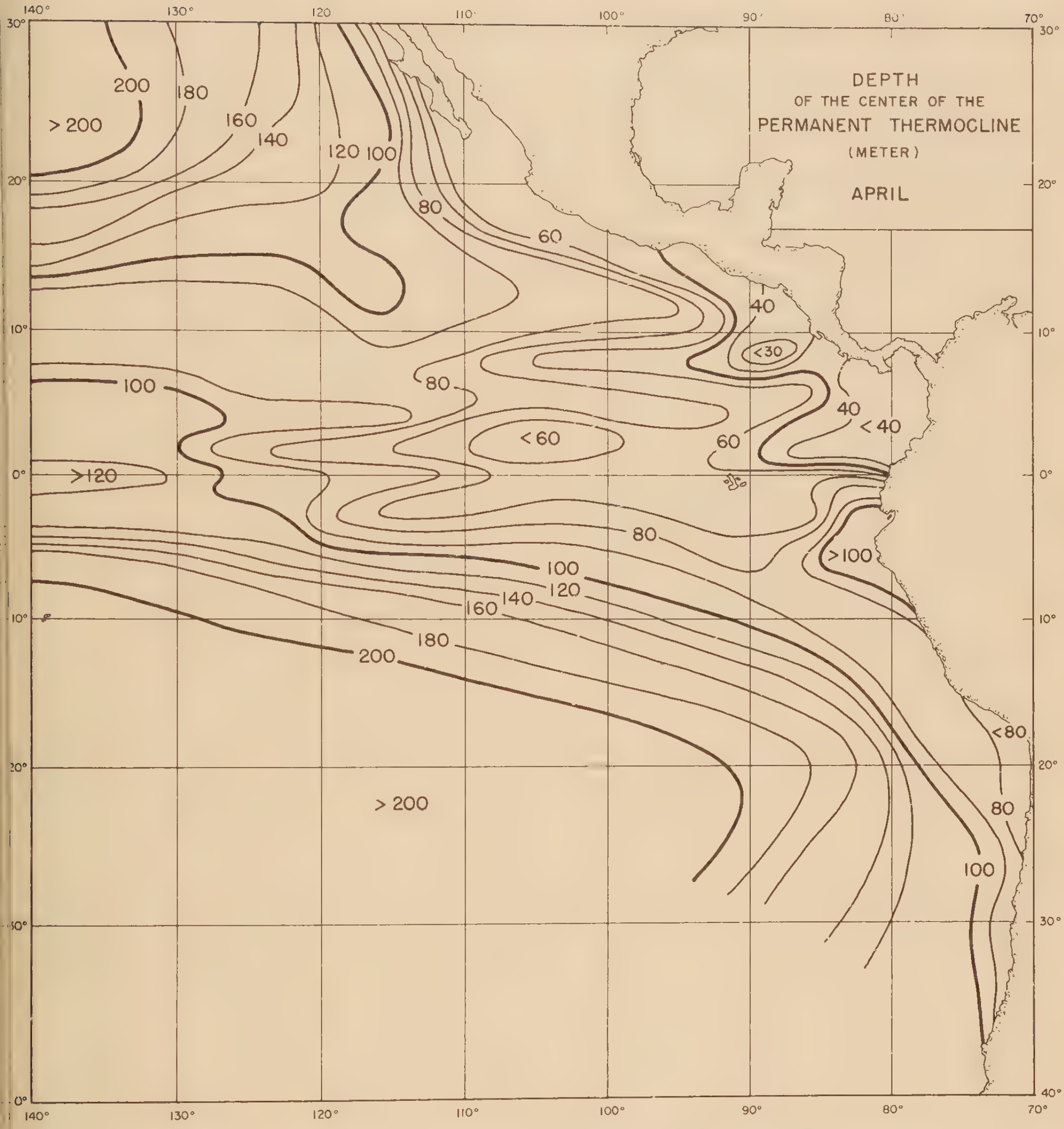

Fig. 45. Depth of the centre of the permanent thermocline in meters in April

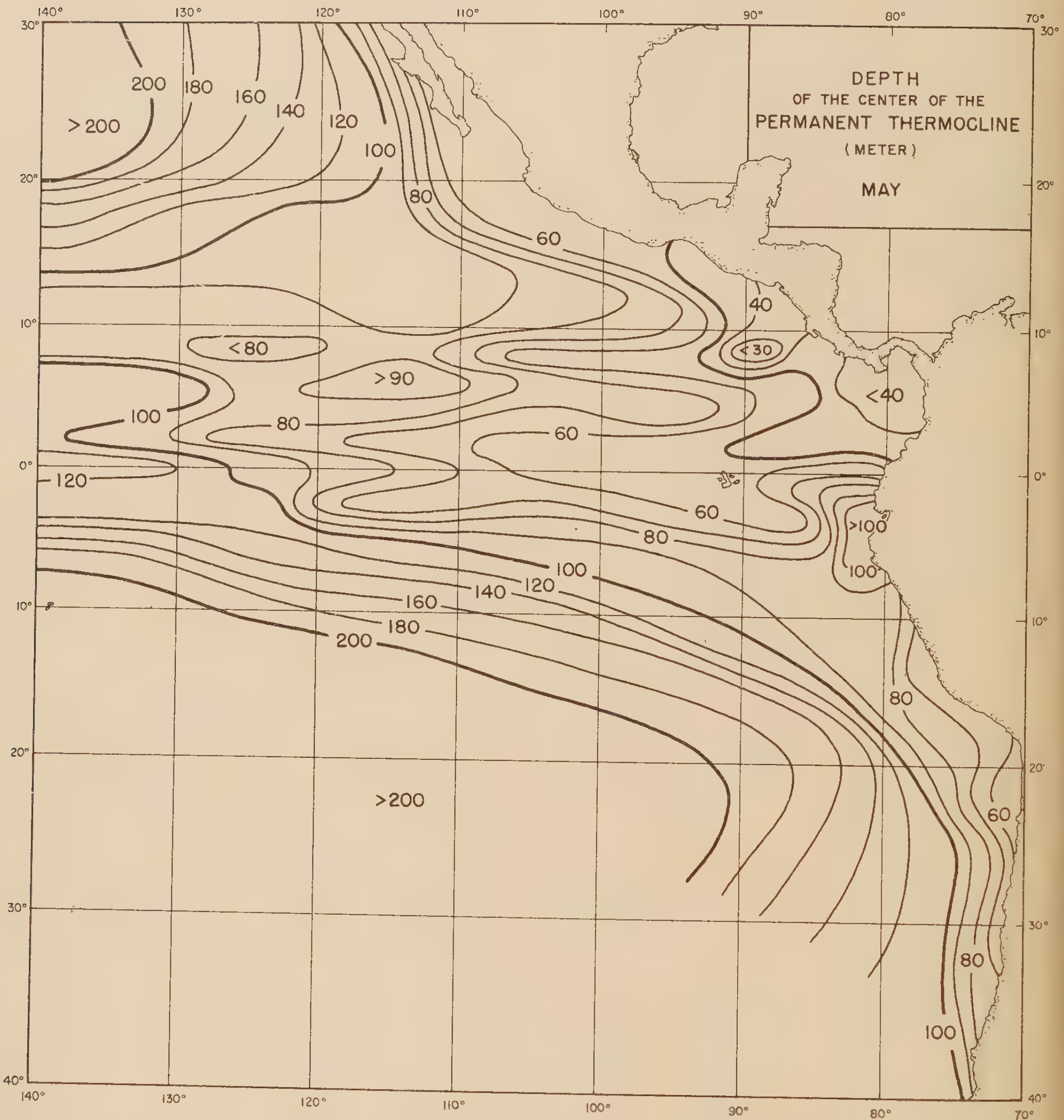

Fig. 46. Depth of the centre of the permanent thermocline in meters in May

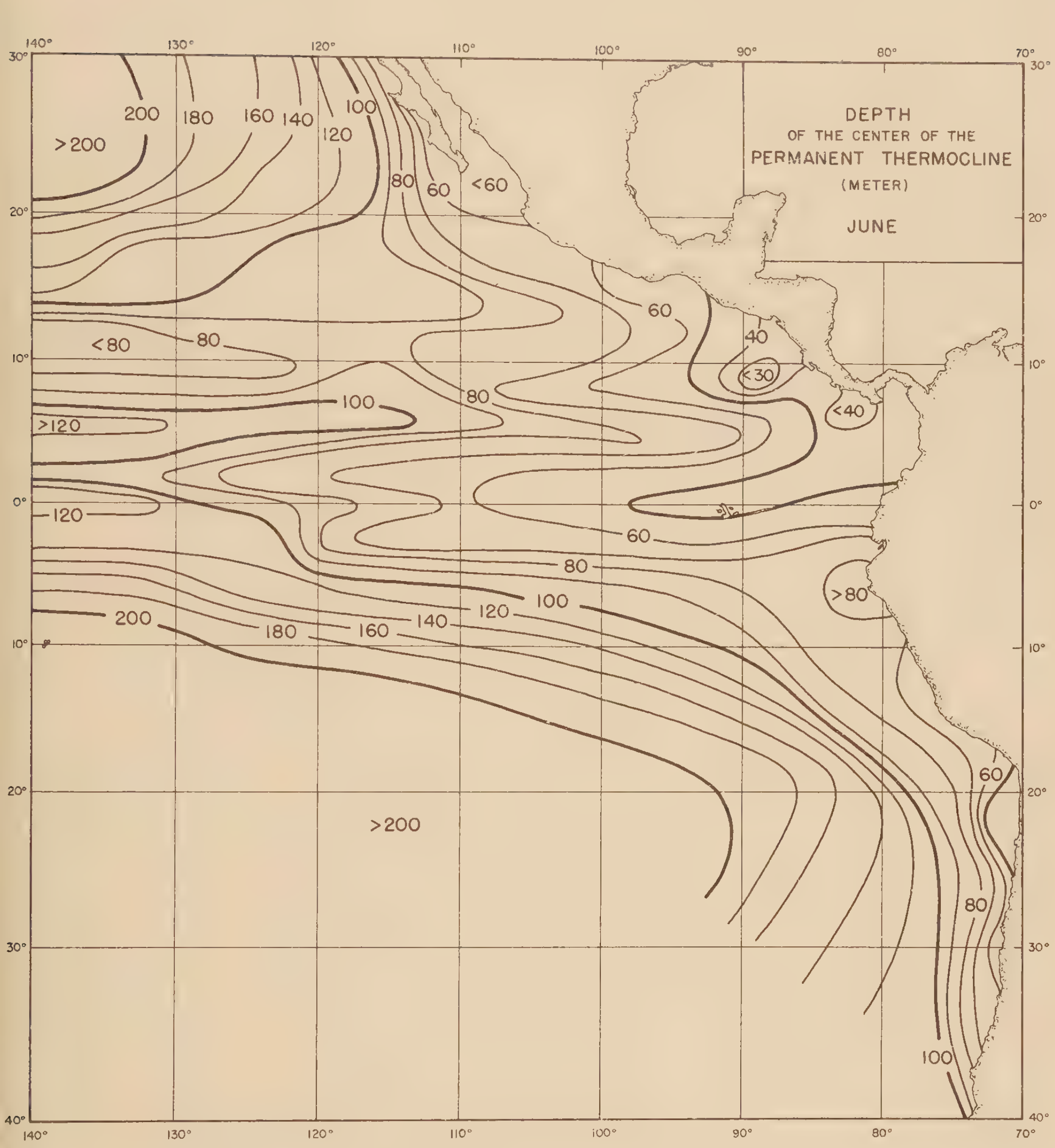

Fig. 47. Depth of the centre of the permanent thermocline in meters in June

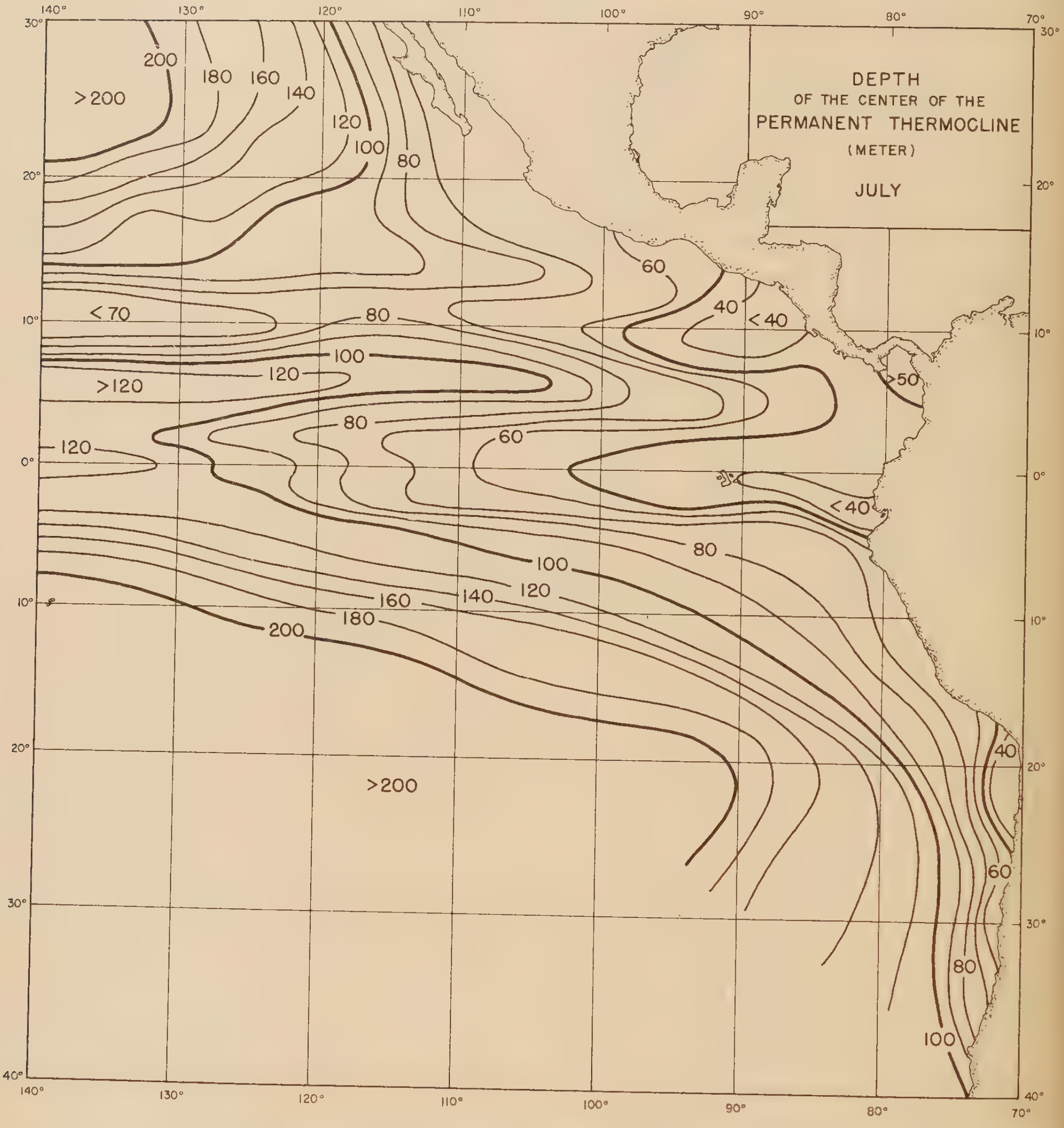

Fig. 48. Depth of the centre of the permanent thermocline in meters in July

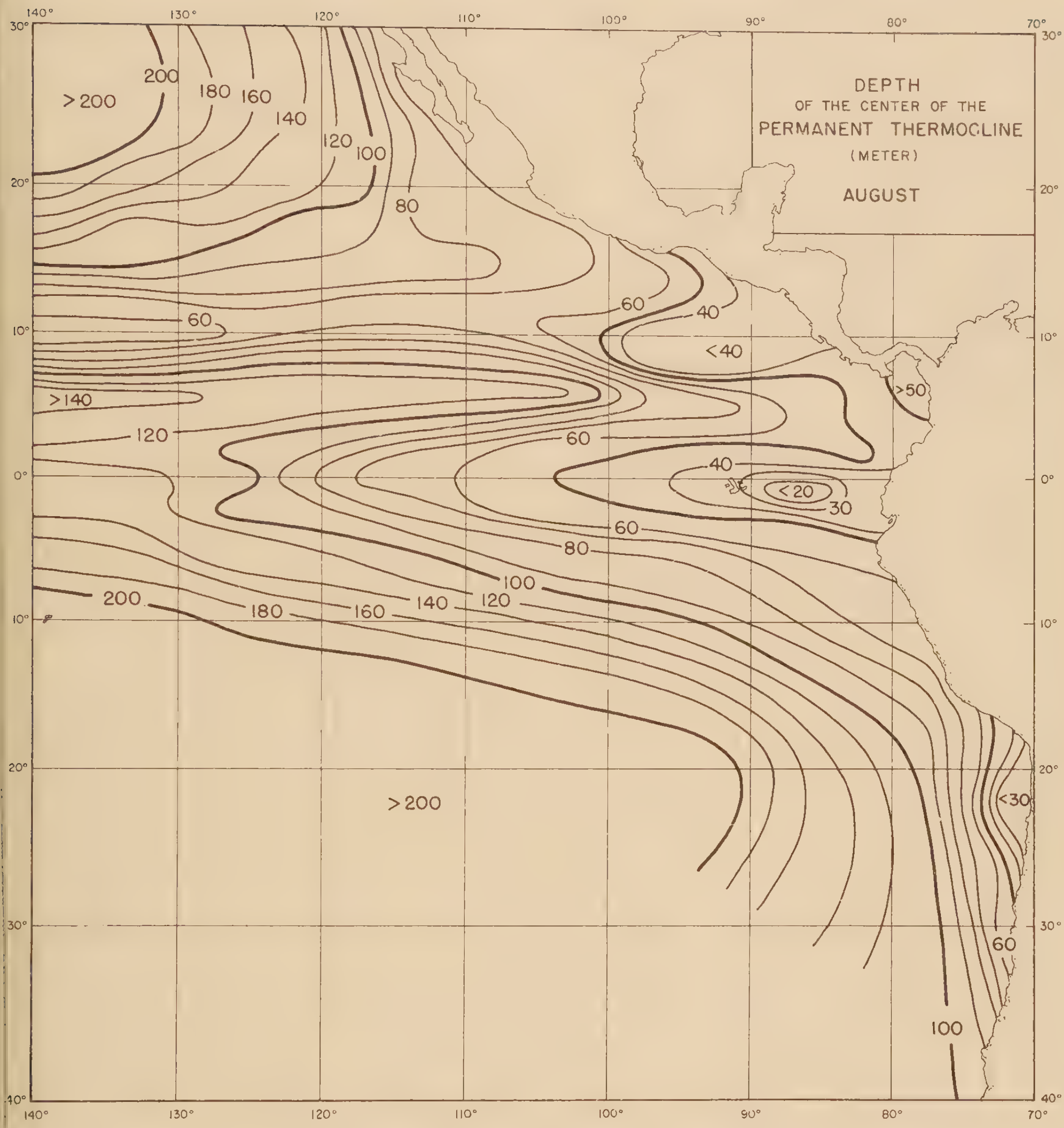

Fig. 49. Depth of the centre of the permanent thermocline in meters in August

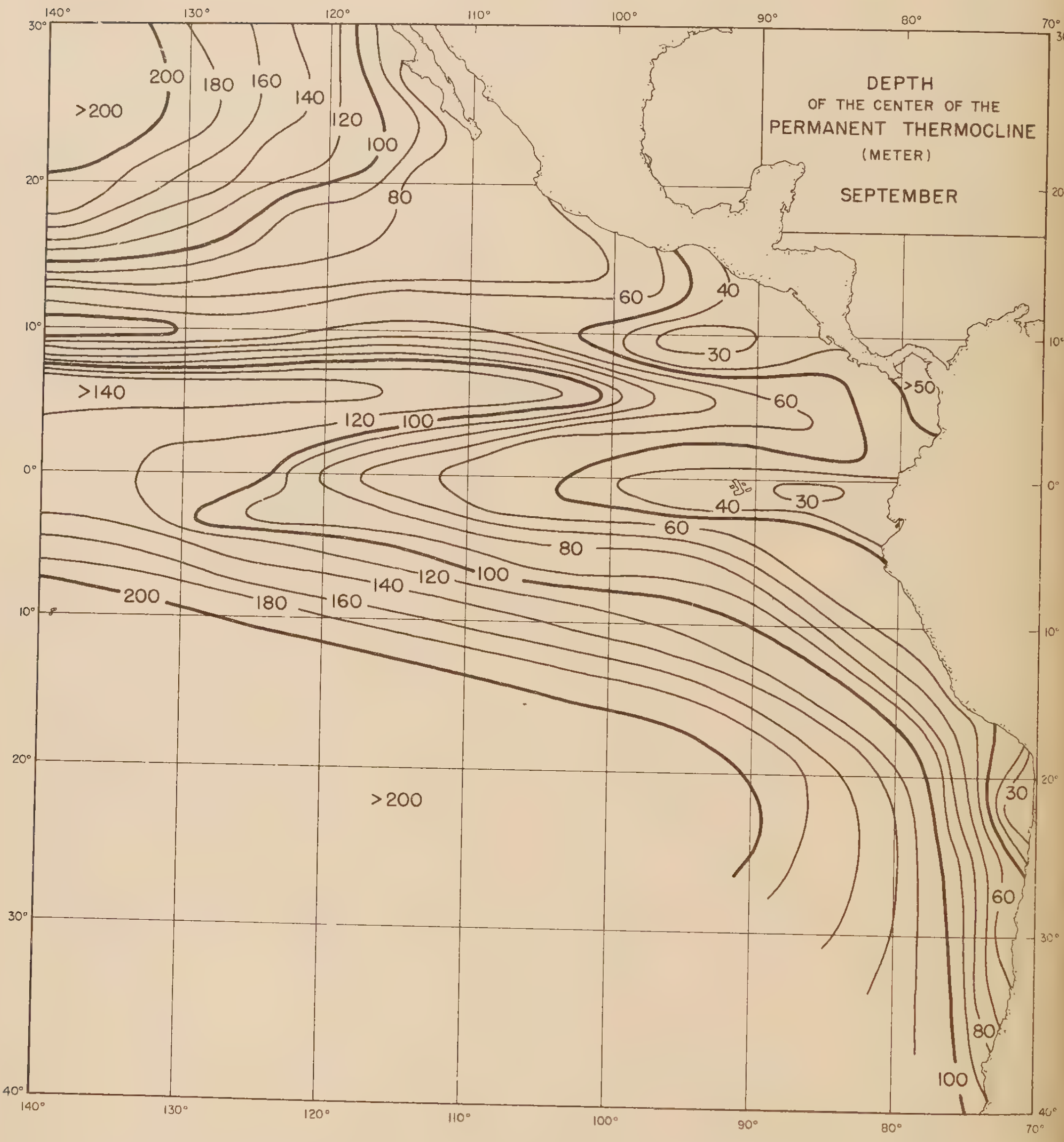

Fig. 50. Depth of the centre of the permanent thermocline in meters in September

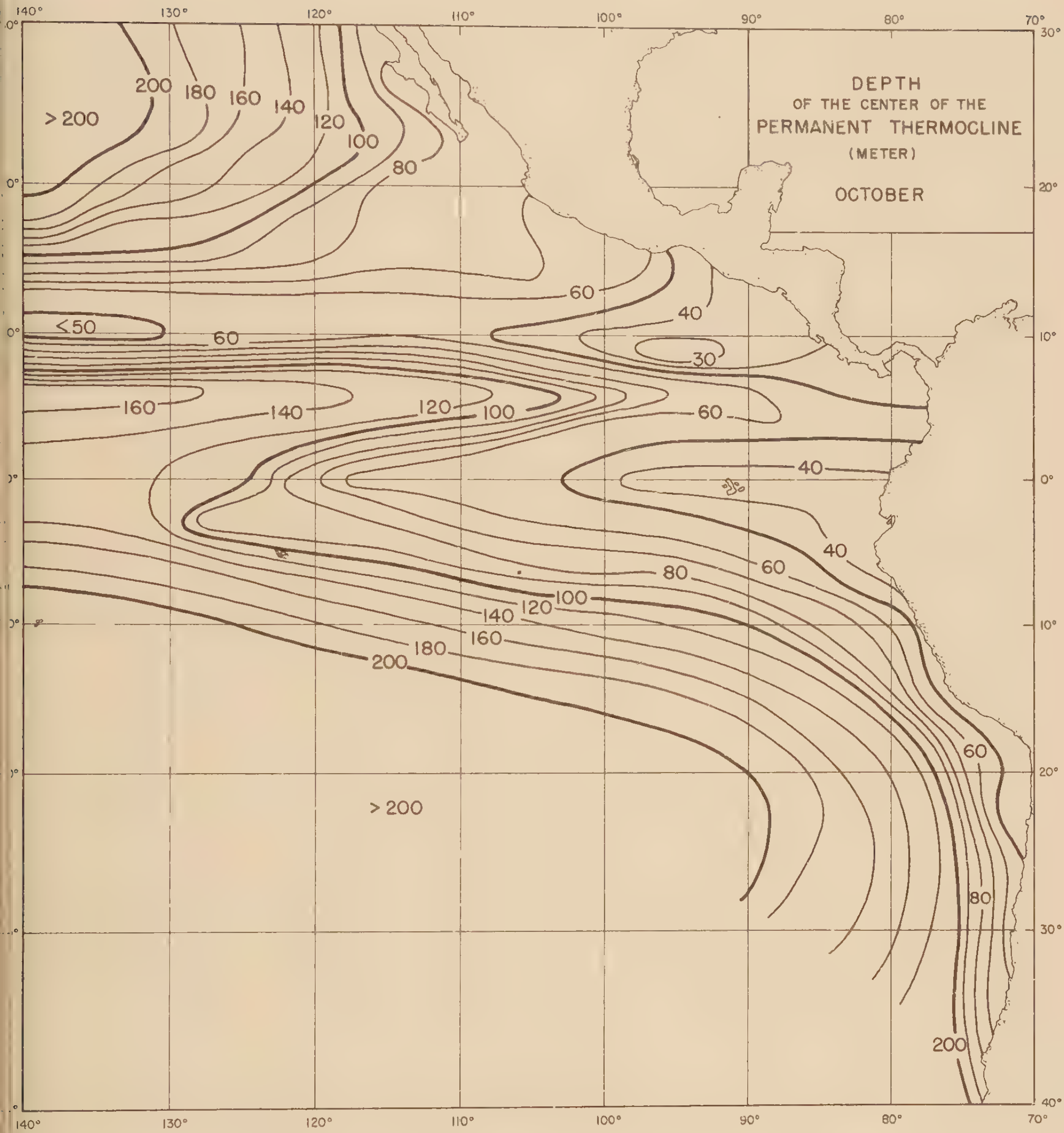

Fig. 51. Depth of the centre of the permanent thermocline in meters in October

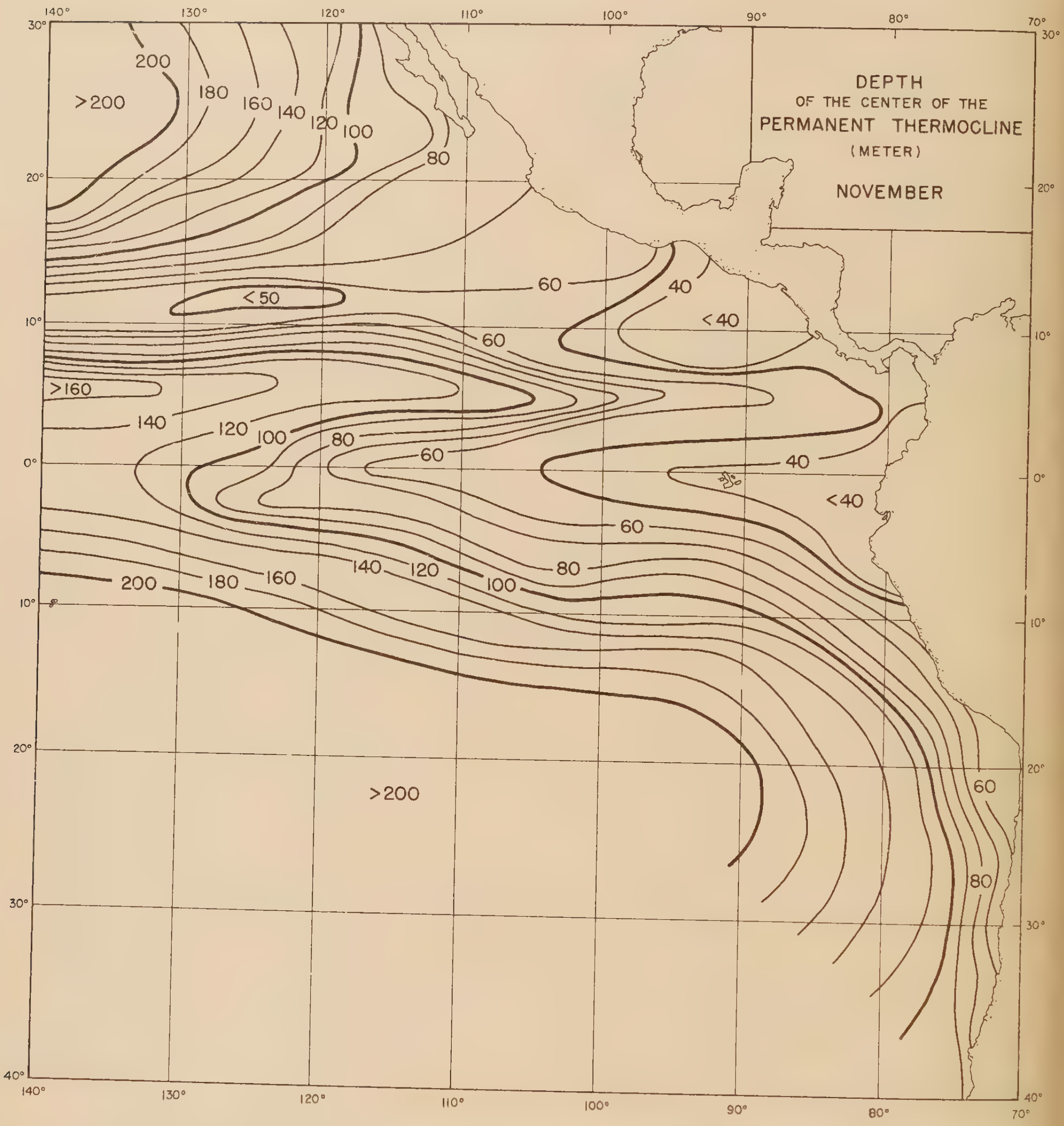

Fig. 52. Depth of the centre of the permanent thermocline in meters in November

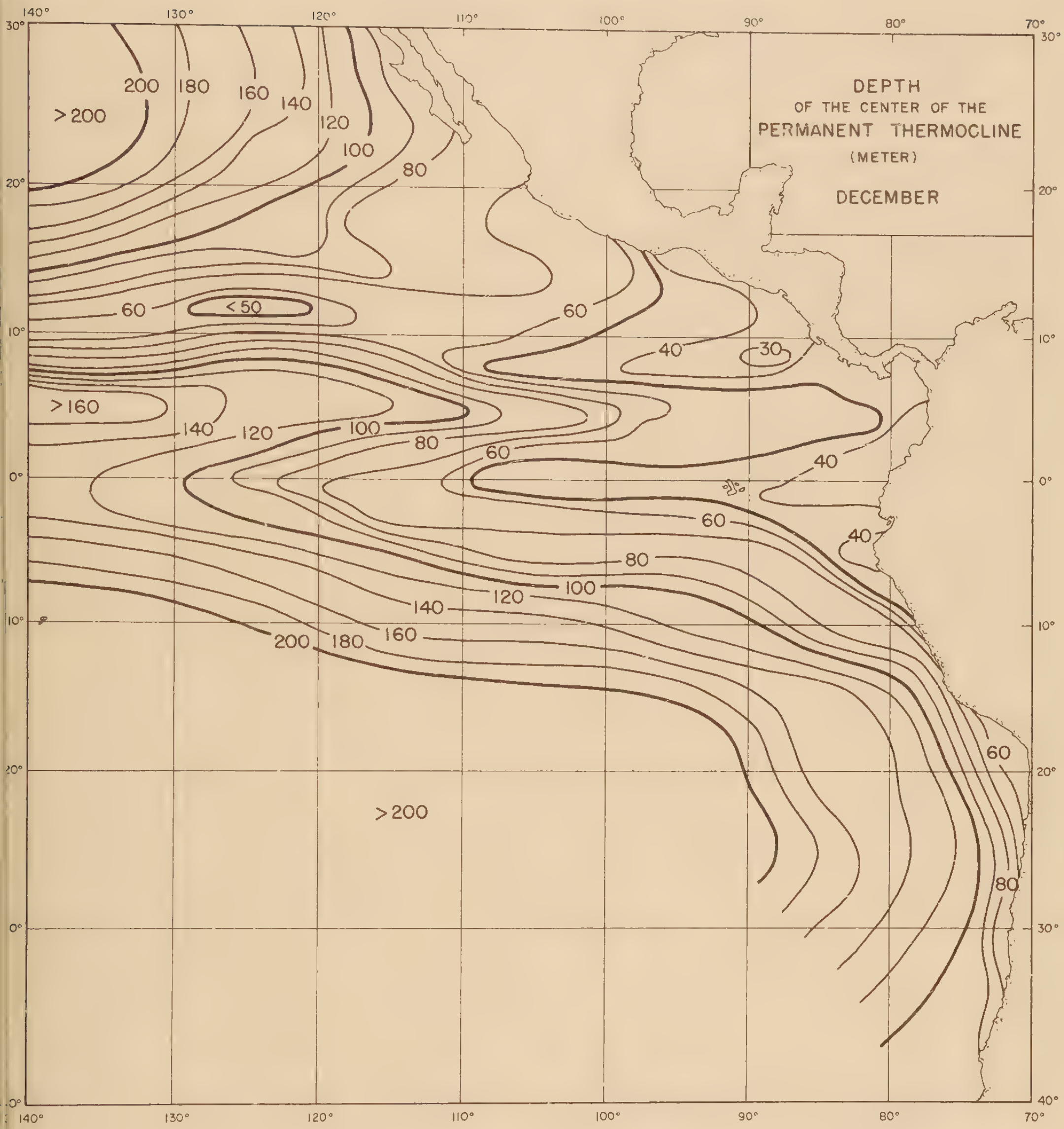

Fig. 53. Depth of the centre of the permanent thermocline in meters in December

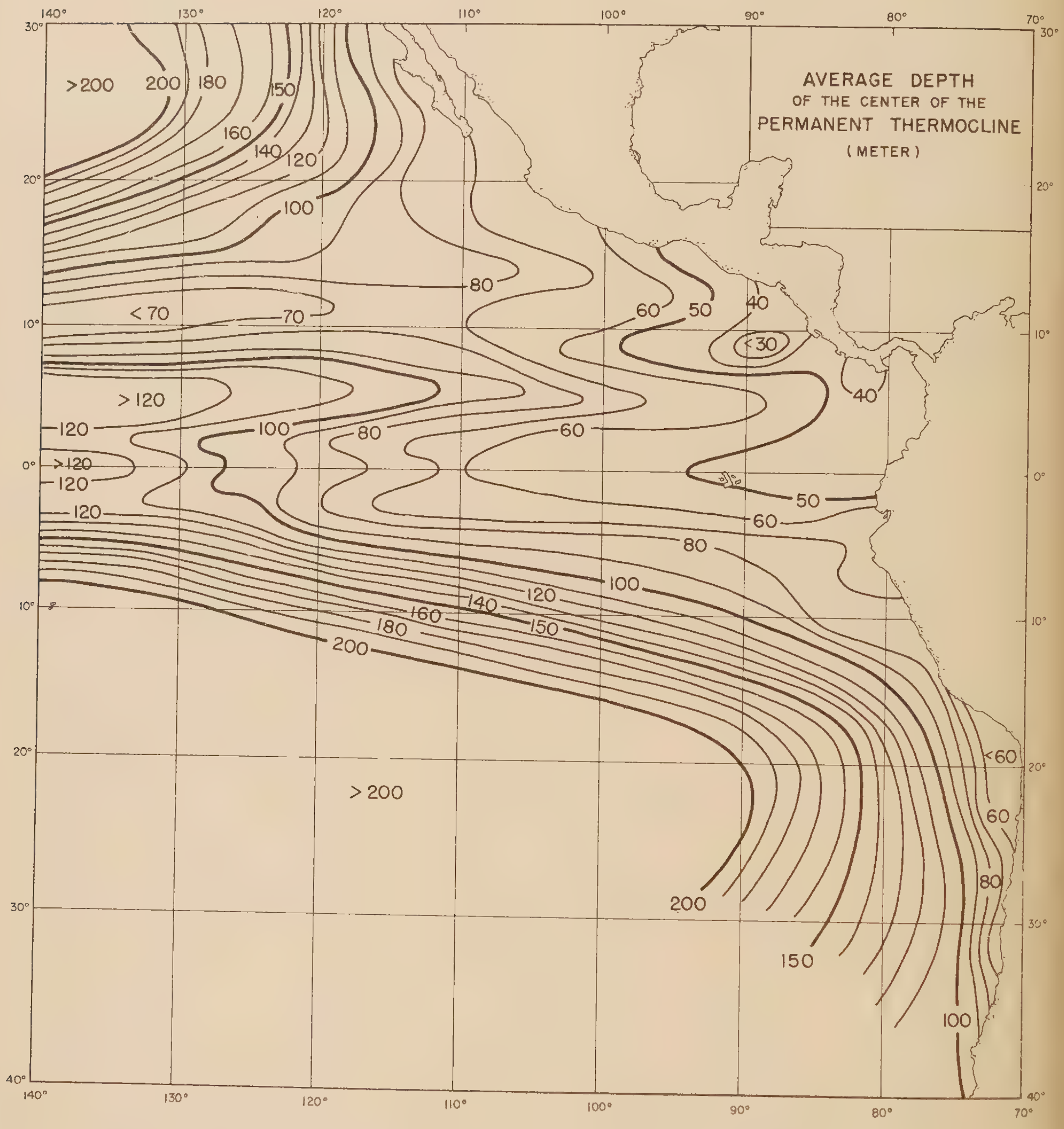

Fig. 54. Average depth of the centre of the permanent thermocline in meters

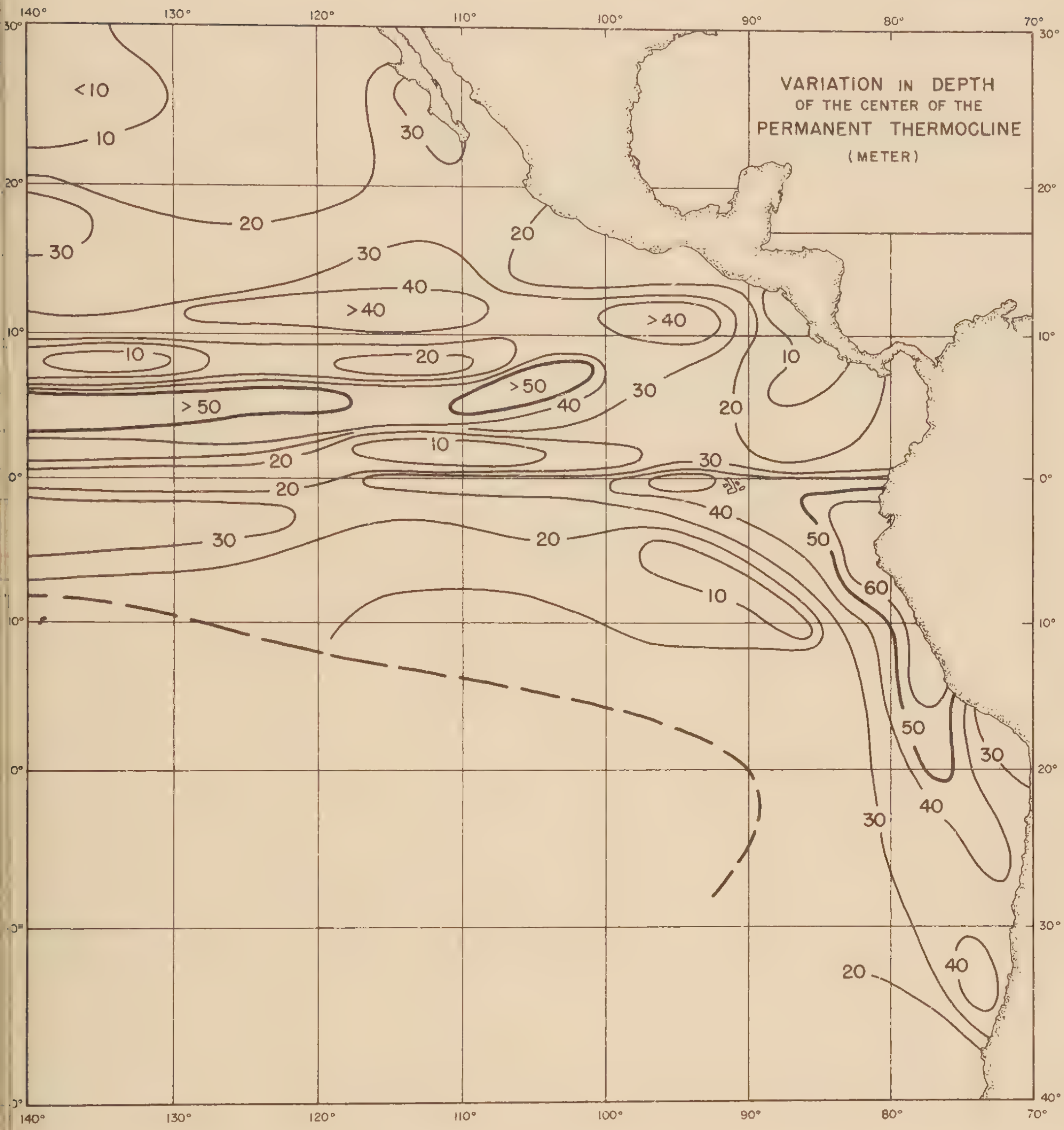

Fig. 55. Variation of the depth of the centre of the permanent thermocline in meters

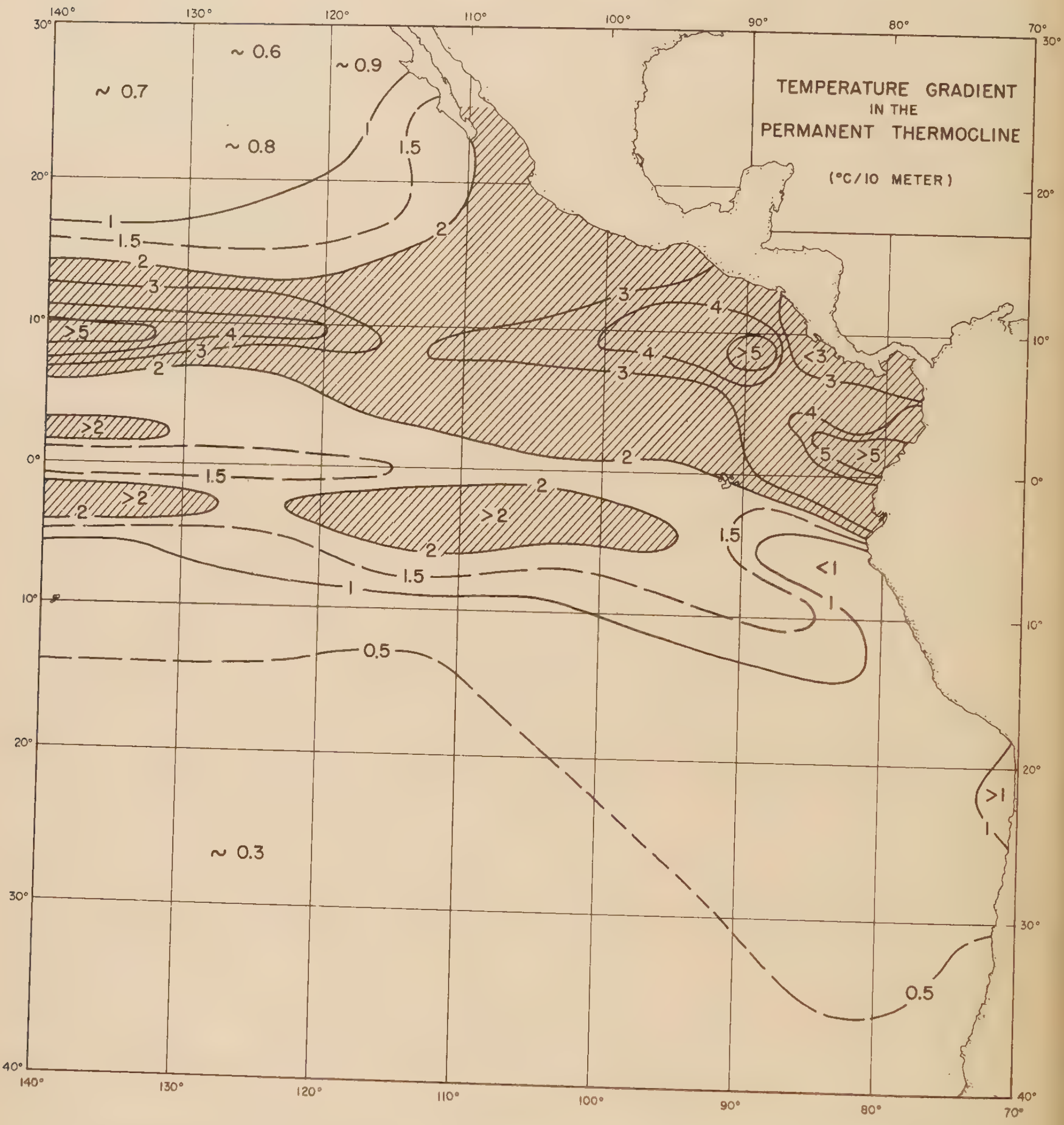

Fig. 56. Temperature gradient in the permanent thermocline in °C/10 meters. > 2°C/10 meters hatched

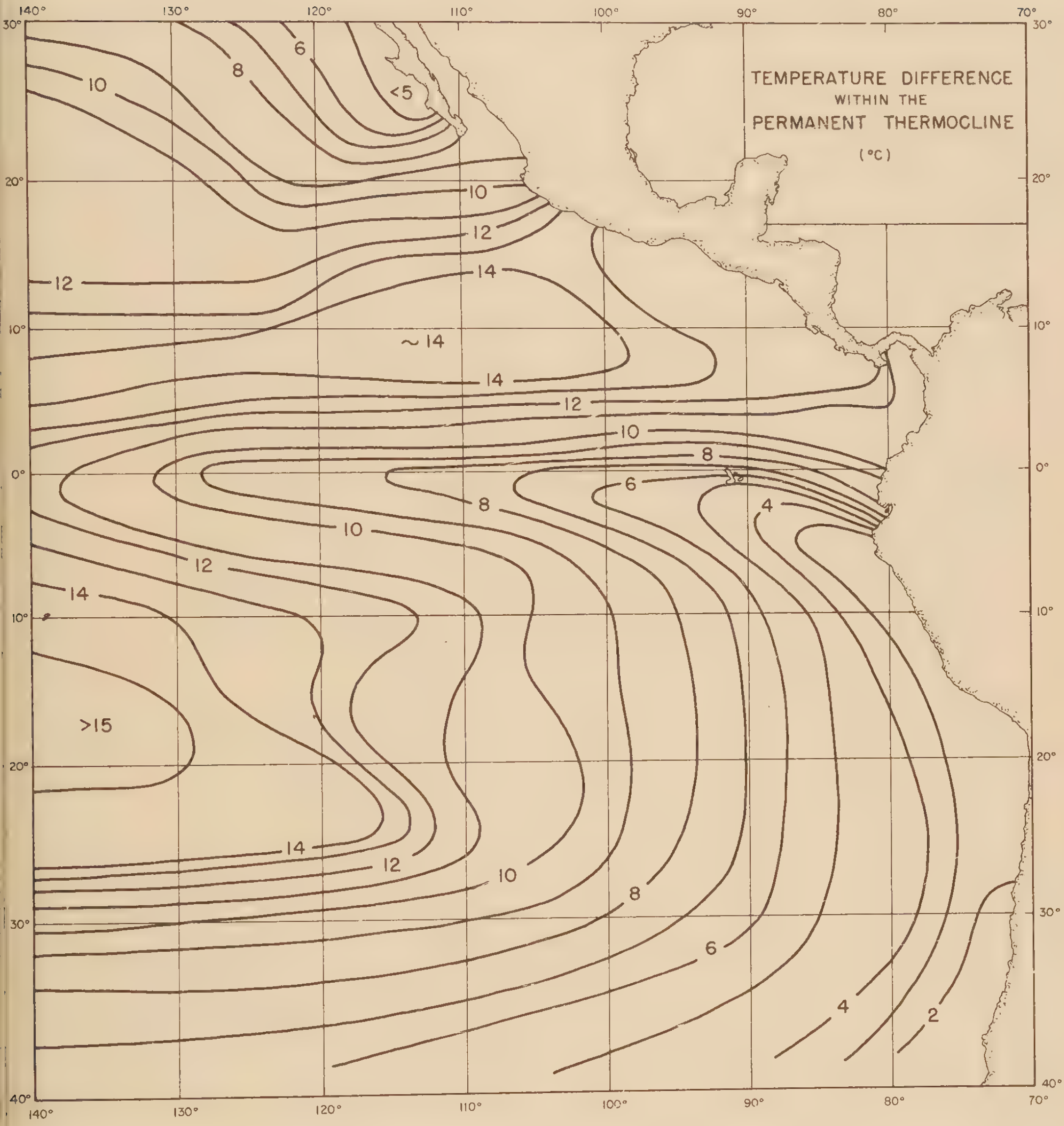

Fig. 57. Temperature difference between the top and the bottom of the permanent thermocline in °C

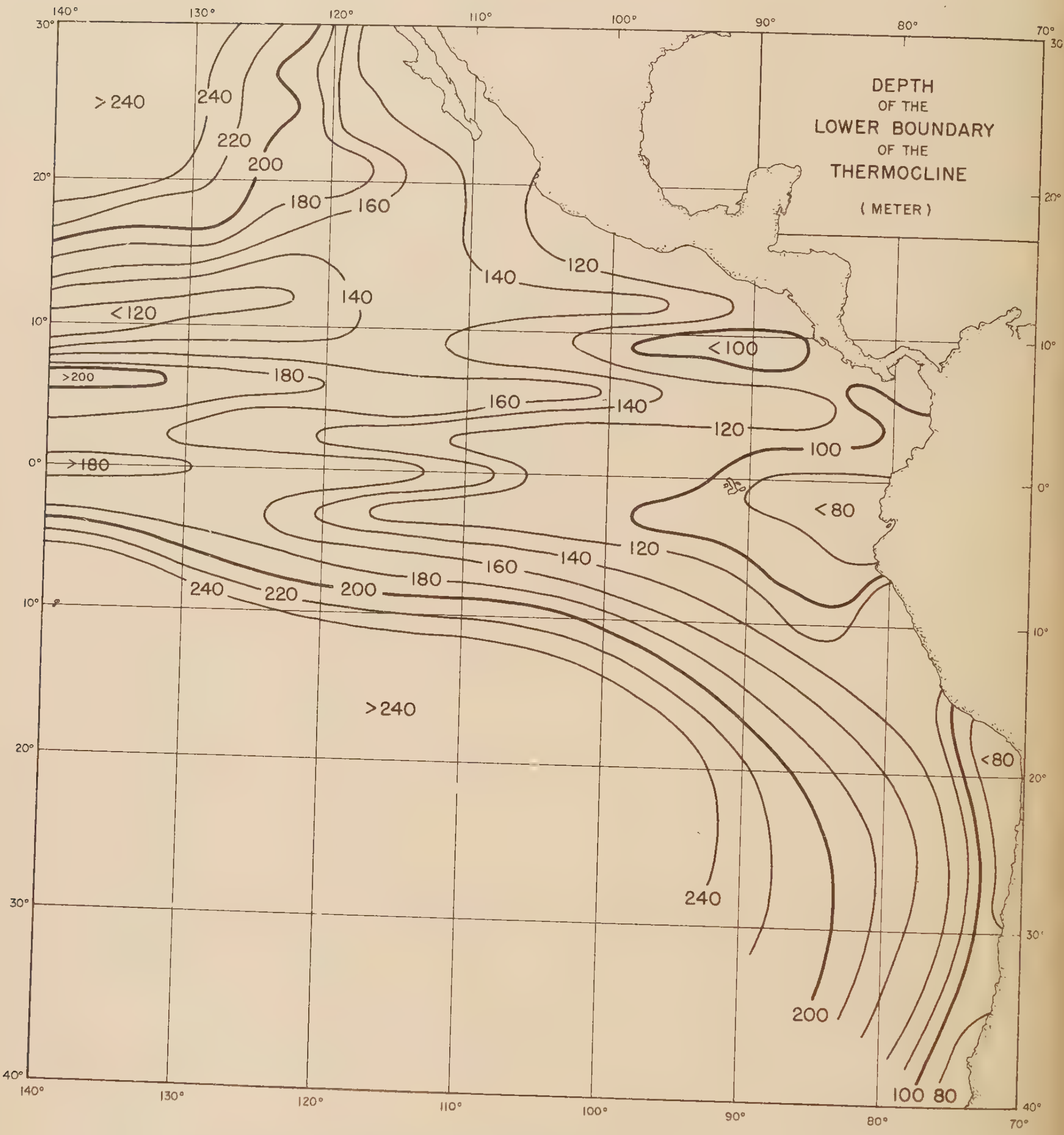

Fig. 58. Depth of the lower boundary of the thermocline in meters, given by the depth, where the temperature gradient decreases to less than 0.3° C/10 meters

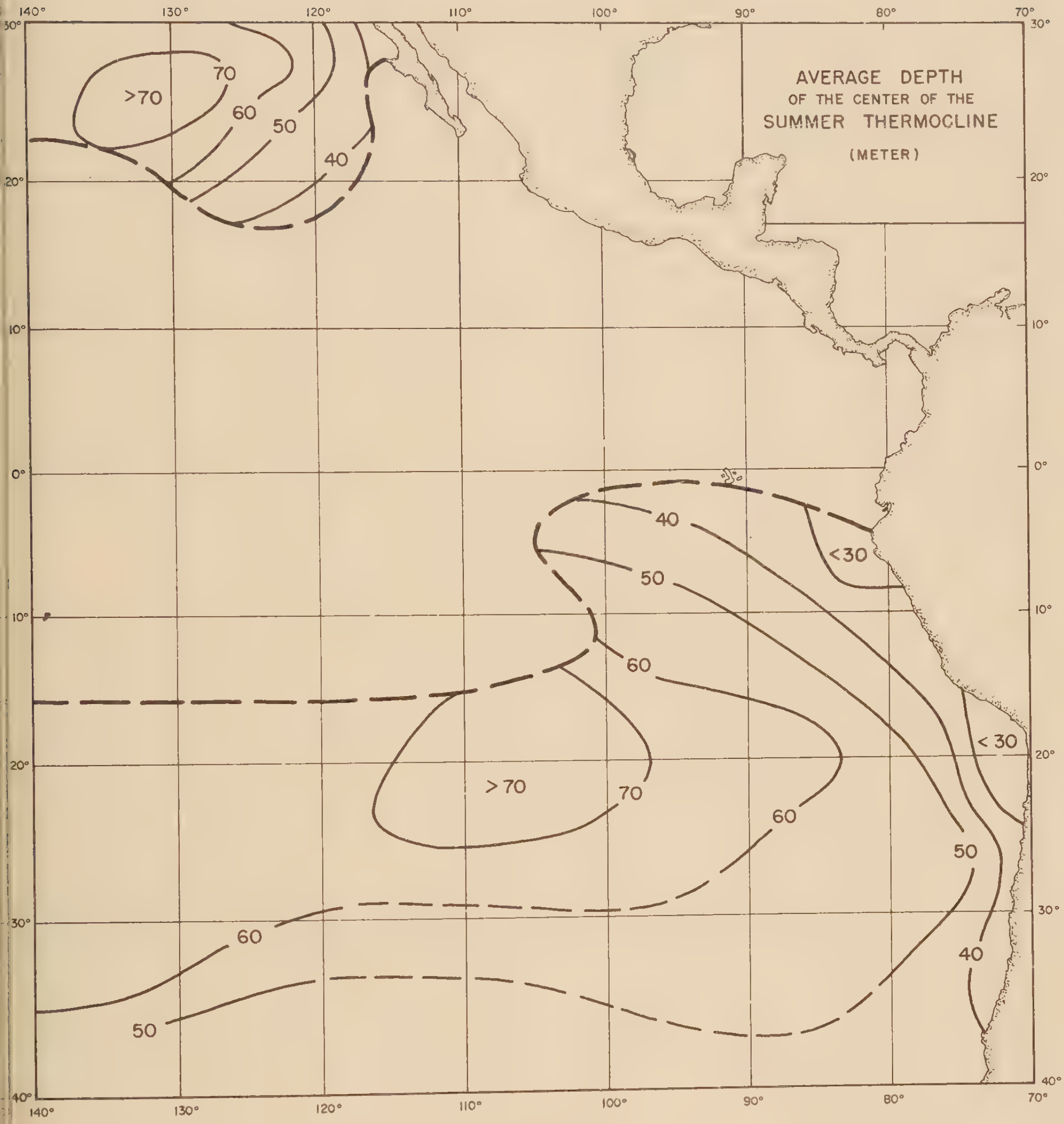

Fig. 59. Average depth of the centre of the summer thermocline in meters. The heavy broken line gives the limit of the area with a summer thermocline

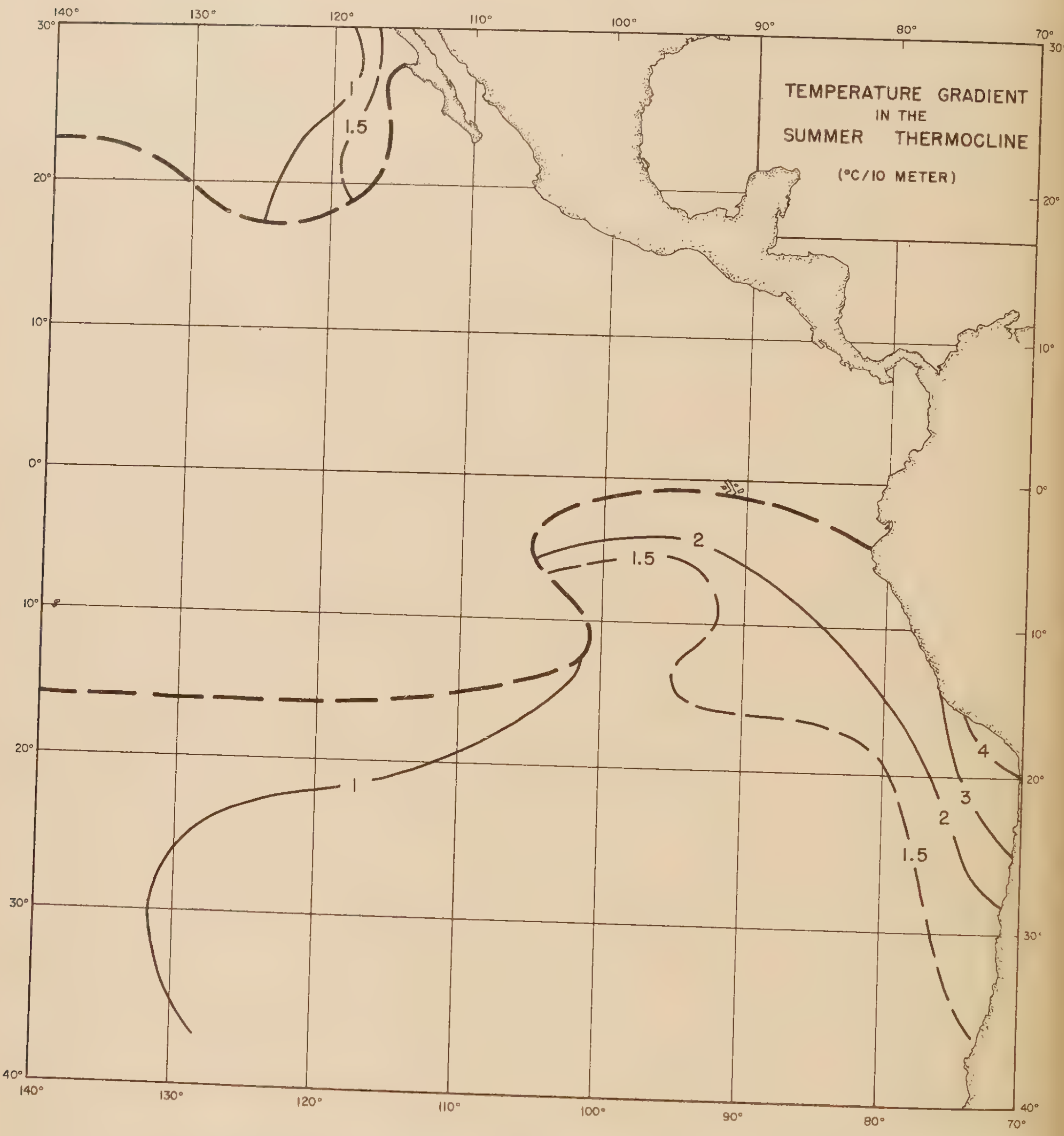

Fig. 60. Temperature gradient in the summer thermocline in °C/10 meters

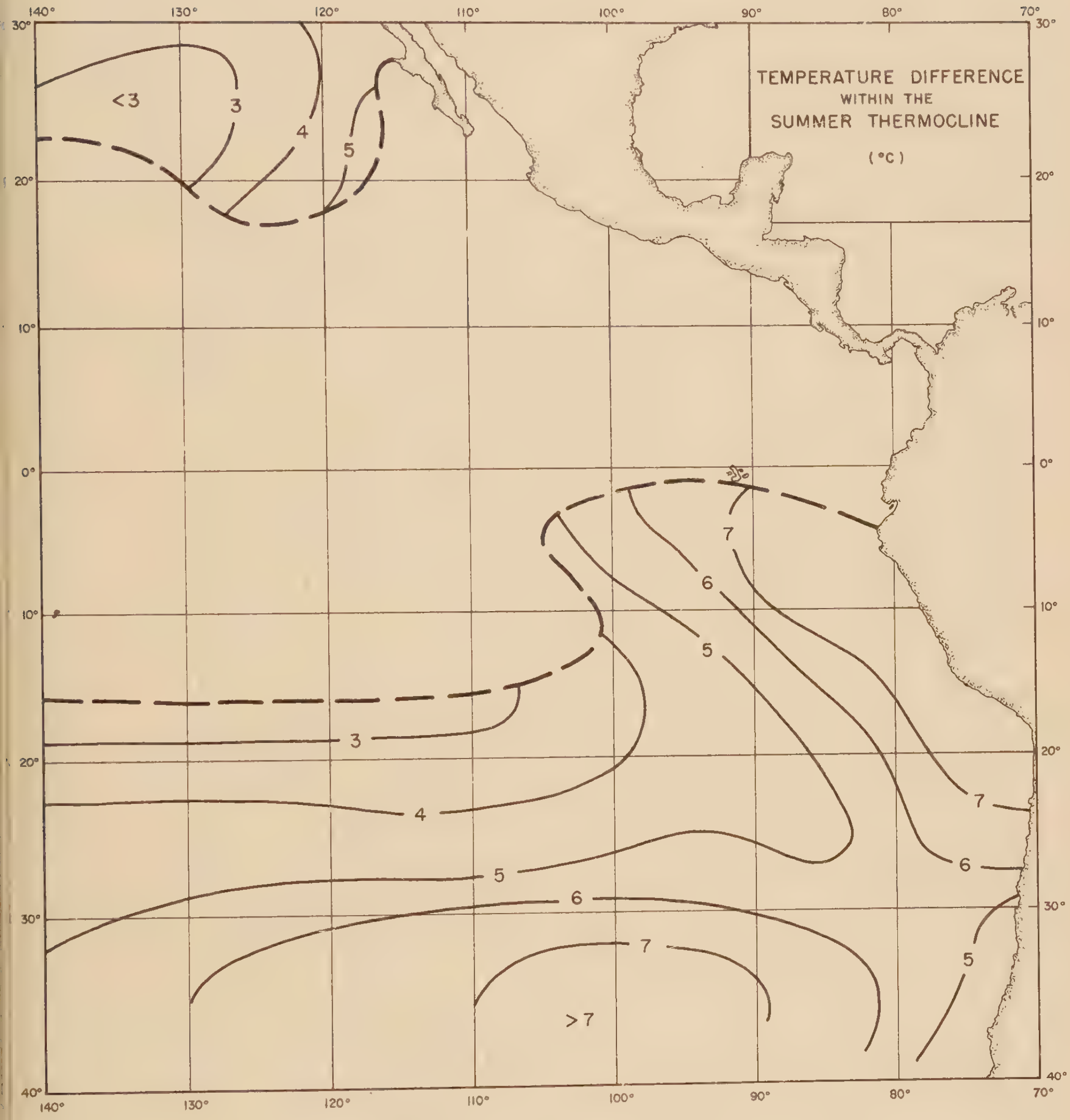

Fig. 61. Temperature difference between the top and the bottom of the summer thermocline in °C

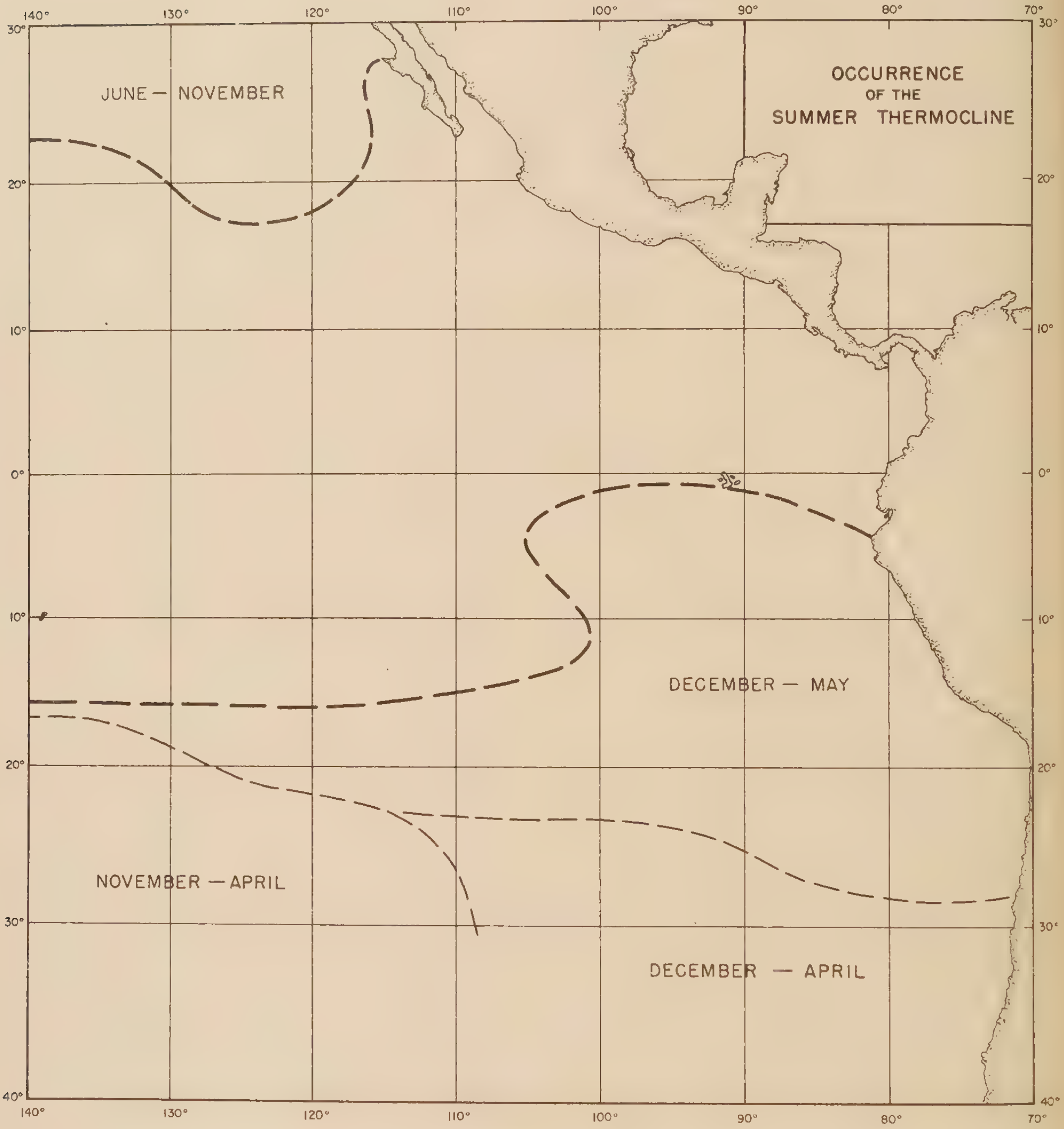

Fig. 62. Occurrence of a summer thermocline

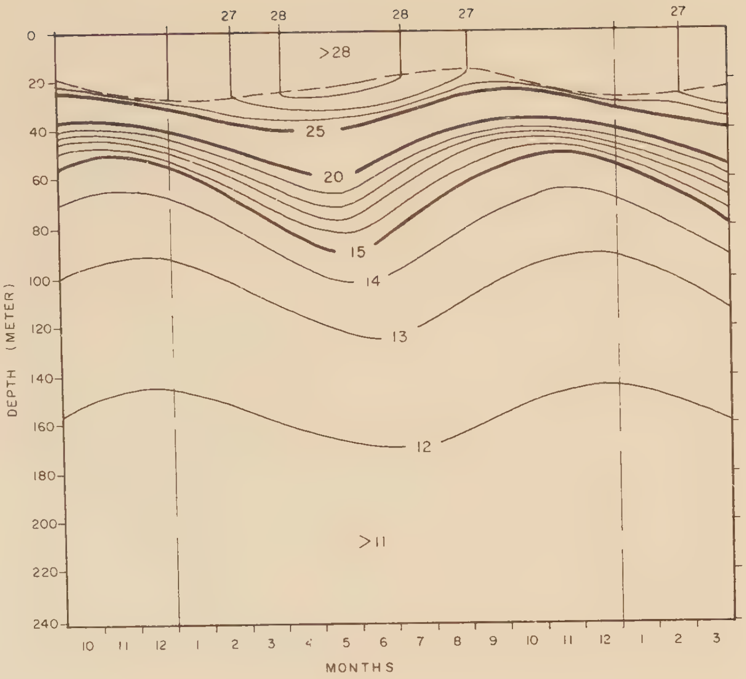

Fig. 63. Variation of the thermal structure during the year near 8° N, 95° W in the eastern tropical Pacific Ocean. Type P, permanent shallow thermocline

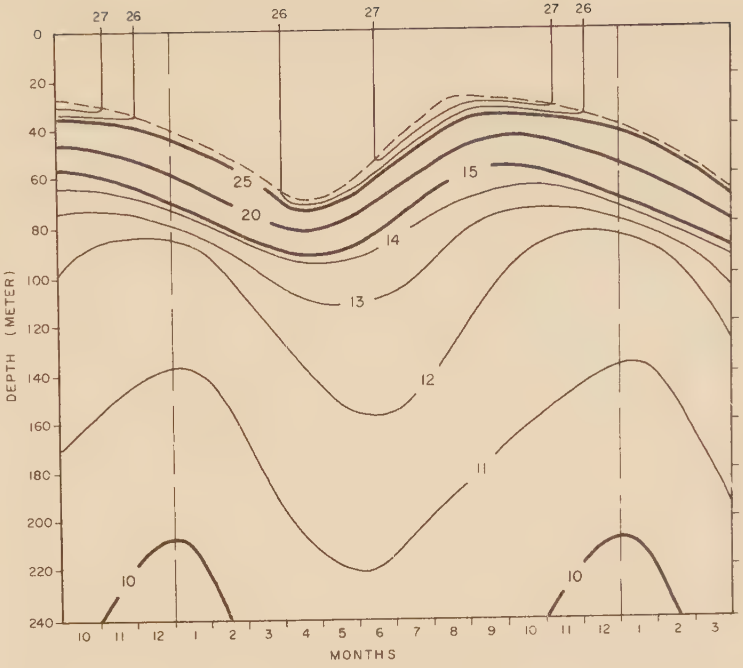

Fig. 64. Variation of the thermal structure during the year near 10° N, 135° W at the northern boundary of the Equatorial Countercurrent. Type P, permanent shallow thermocline

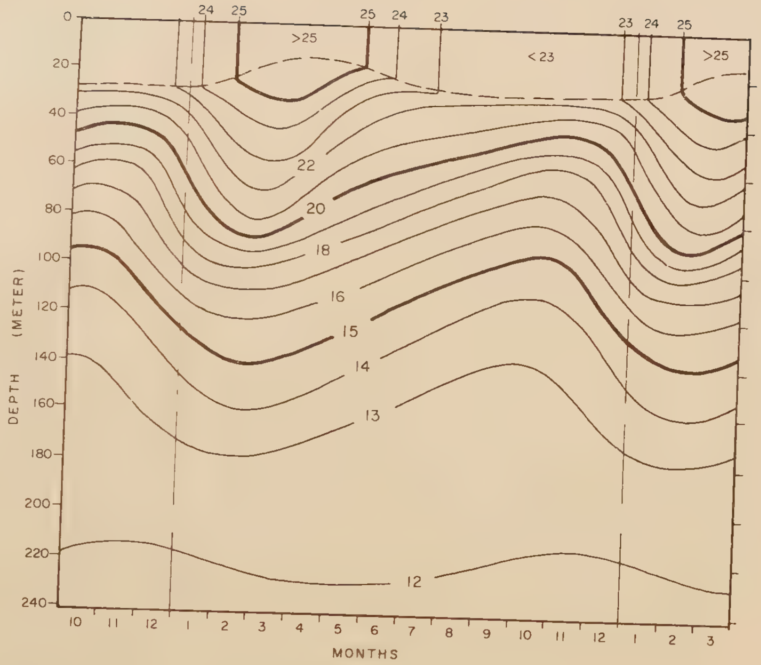

Fig. 65. Variation of the thermal structure during the year at the equator near 115° W in the Equatorial Undercurrent. Type P, permanent shallow thermocline

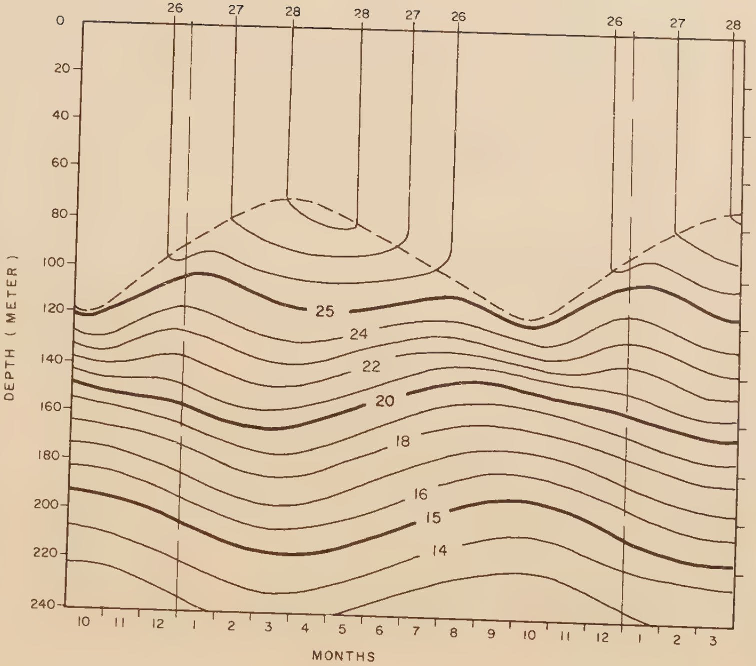

Fig. 66. Variation of the thermal structure during the year near 7° S, 135° W in the South Equatorial Current. Type D, permanent deep thermocline

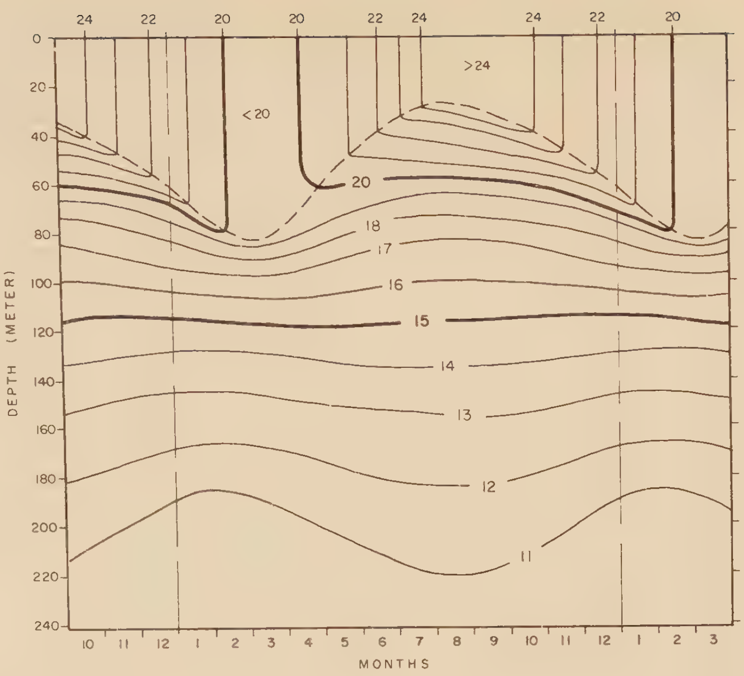

Fig. 67. Variation of the thermal structure during the year near 21°N, 118°W in the southern parts of the California Current. Type PS, permanent shallow thermocline with summer thermocline

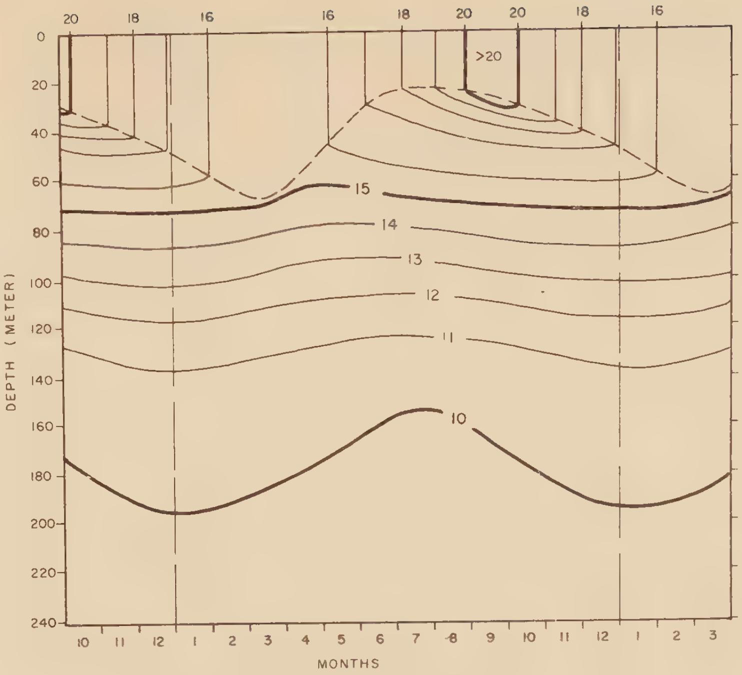

Fig. 68 Variation of the thermal structure during the year near 29°N, 116°W in the upwelling region off Baja California. Type PS, permanent shallow thermocline with summer thermocline

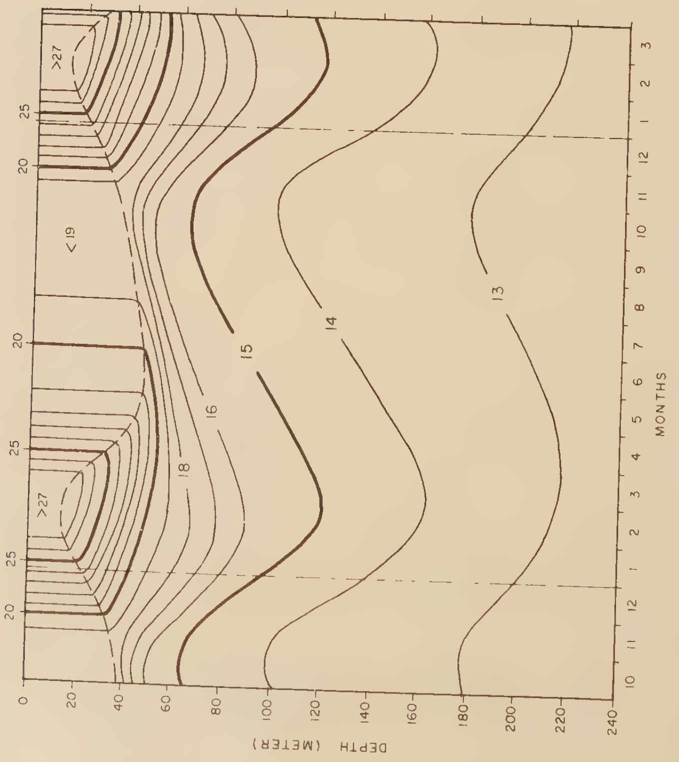

Fig. 69. Variation of the thermal structure during the year near 7°S, 88° W in the Peru Current. Type PS, permanent shallow thermocline with summer thermocline

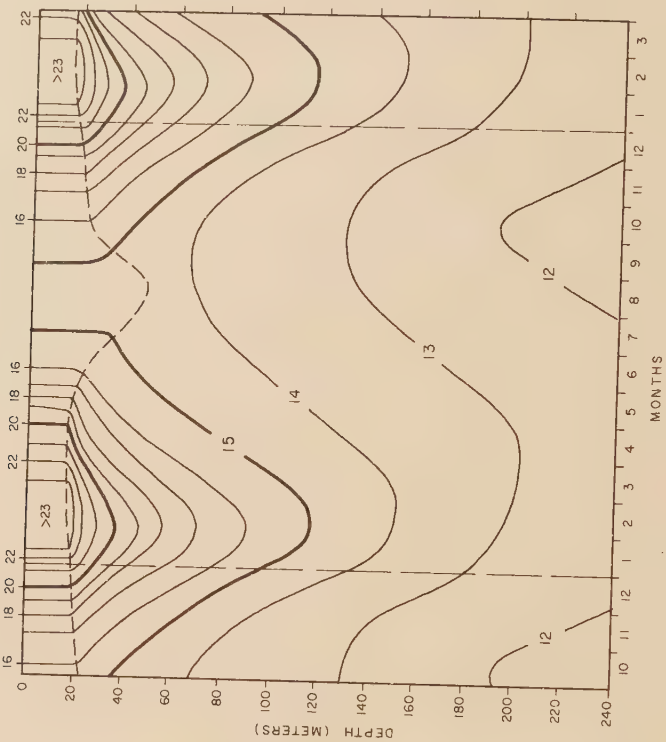

Fig. 70. Variation of the thermal structure during the year near 11°S, 79° W in the upwelling region off Peru. Type PS, permanent shallow thermocline with summer thermocline

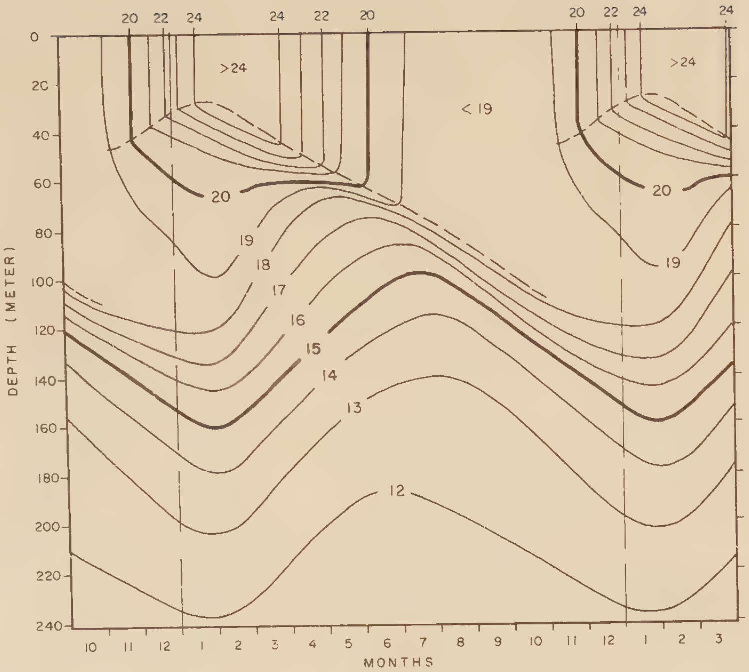

Fig. 71. Variation of the thermal structure during the year near 15°S, 86° W in the Peru Current. Type PSW, permanent shallow thermocline with summer thermocline and deep mixed layer during winter

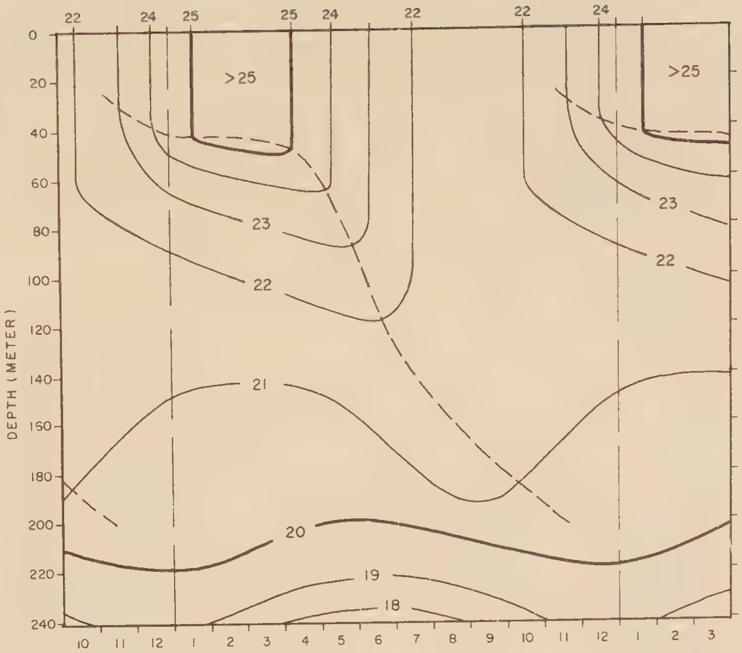

Fig. 72. Variation of the thermal structure during the year near 25°S, 115° W in the central South Pacific Ocean. Type DSW, permanent deep thermocline with summer thermocline and deep mixed layer during winter

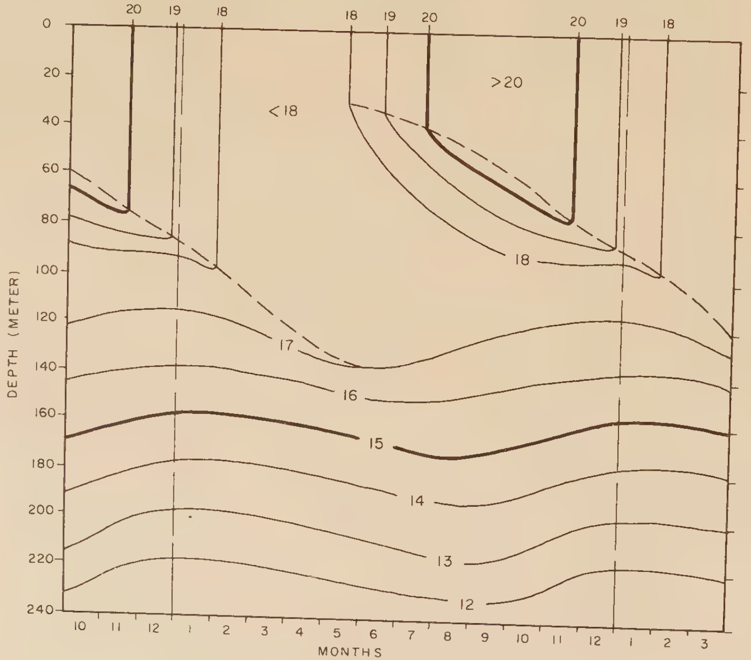

Fig. 73. Variation of the thermal structure during the year near 29° N, 132° W Type DSW, permanent deep thermocline with summer thermocline and deep mixed layer during winter

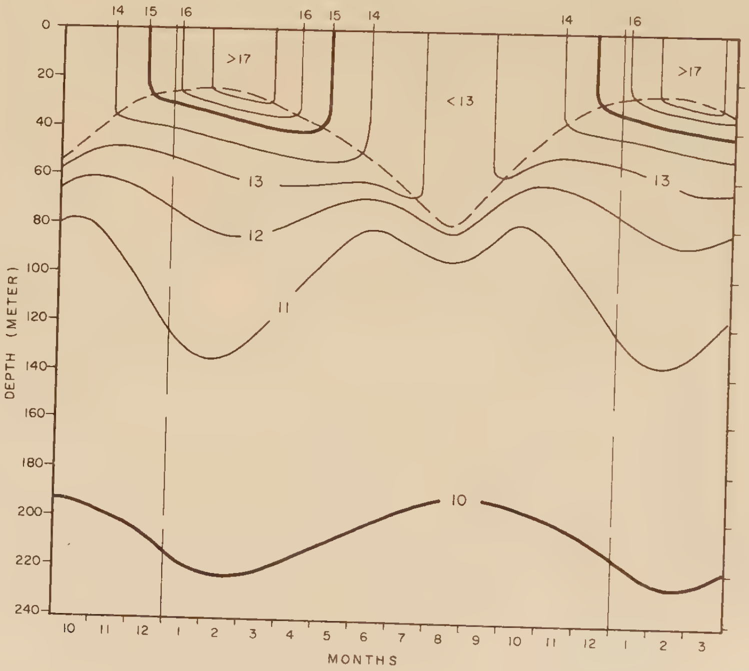

Fig. 74. Variation of the thermal structure during the year near 33° S, 77° W off the coast of Chile. Type S, summer thermocline only

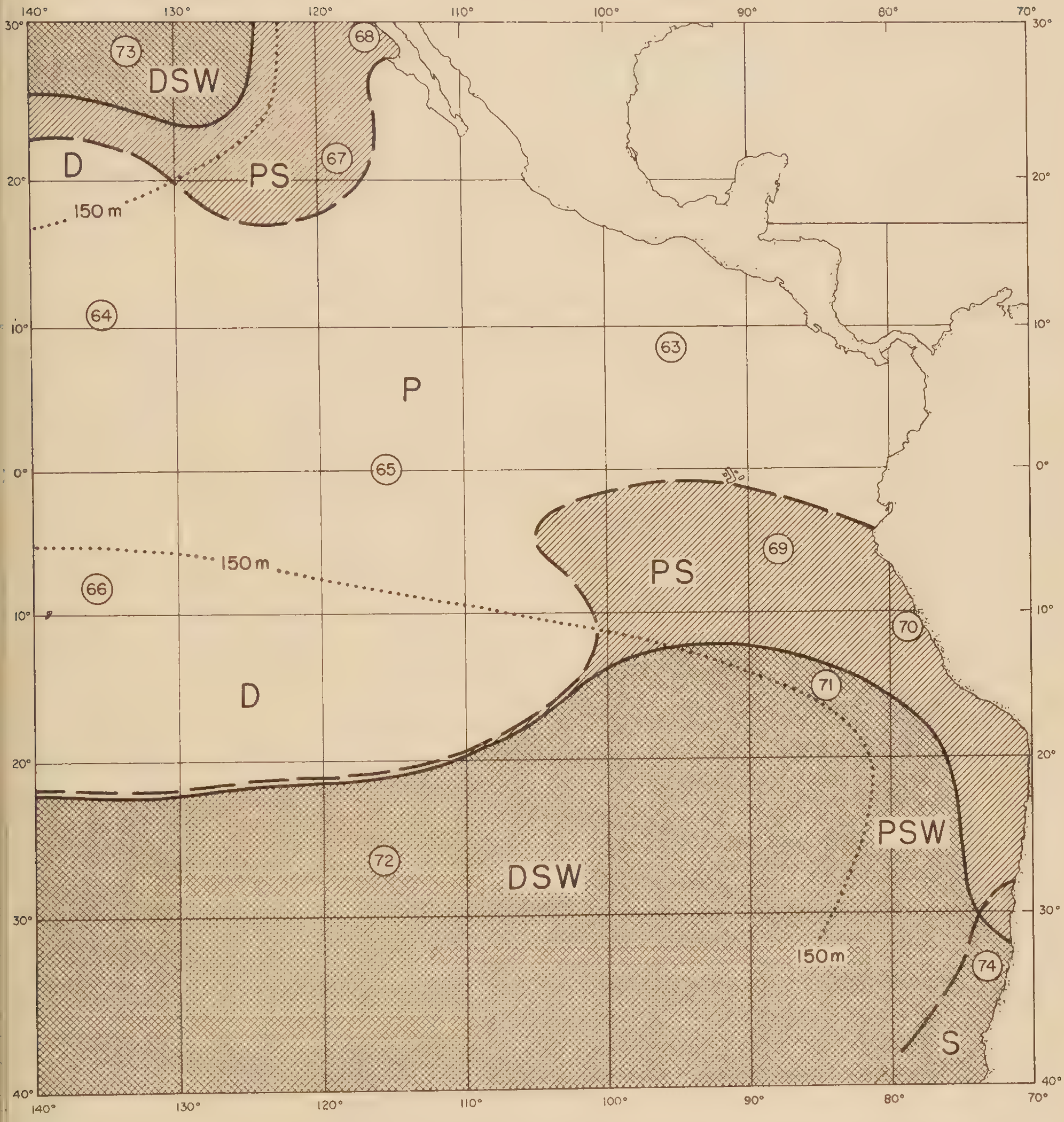

Fig. 75. Distribution of types of thermal structure in the eastern Pacific Ocean:
P: permanent shallow thermocline,
D: permanent deep thermocline,
PS: permanent thermocline with summer thermocline,
PSW: permanent shallow thermocline with summer thermocline and deep mixed layer during winter,
DSW: permanent deep thermocline with summer thermocline and deep mixed layer in winter,
S: summer thermocline only
The dotted line indicates the boundary of the area, where the centre of the permanent thermocline is deeper than 150 metres. Circles with the number of the corresponding figure indicate the locations for which diagrams of the variation of the thermal structure during the year are given

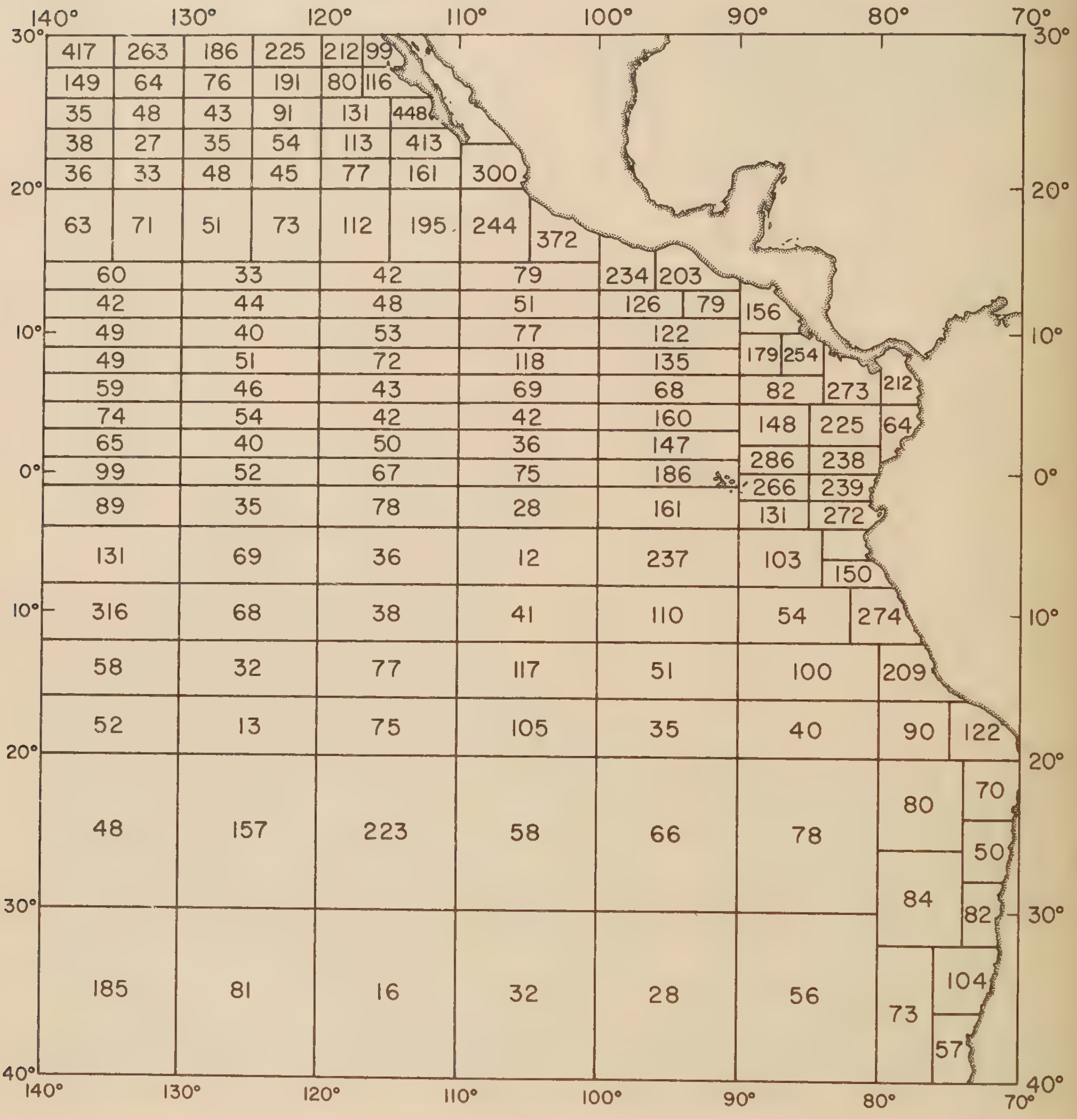

Fig. 76. Number of bathythermograph observations in sub-areas

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UND B